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# QUANTITATIVE CLASSIFICATION OF IGNEOUS ROCKS

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# QUANTITATIVE CLASSIFICATION OF IGNEOUS ROCKS

BASED ON CHEMICAL AND MINERAL CHARACTERS, WITH
A SYSTEMATIC NOMENCLATURE

BY

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WITH AN INTRODUCTORY REVIEW OF THE DEVELOPMENT OF
SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY

BY

WHITMAN CROSS

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TO

WILLIAM F. HILLEBRAND

AND TO HIS ASSOCIATES

CHEMISTS OF THE UNITED STATES GEOLOGICAL SURVEY

IN RECOGNITION OF THEIR SERVICES

TO THE SCIENCE OF PETROLOGY

THIS WORK IS GRATEFULLY DEDICATED BY THE AUTHORS

# PREFACE.

It has seemed advisable, in order to assist petrographers and students of igneous rock who may wish to adopt the method of classification proposed by the authors, to publish in separate form the essays that have appeared in Volume X of the *Journal of Geology*, with the addition of tables to aid in the calculation of mineral and chemical compositions of rocks, and with a glossary of the new terms employed in the nomenclature.

Much of the material will be useful to those, also, who do not follow the new classification, since it has a general application to petrography. Thus the "Review of the Development of Systematic Petrography in the Nineteenth Century" presents a historical sketch of the subject which is valuable to all students of petrology.

The methods of calculation by which the minerals of a rock may be reckoned from its chemical analysis, and the reverse process, will become more and more of a requirement in the practice of petrographers, as the demand for quantitative description increases. And the convenience of tables in carrying on the operation will be appreciated by all who undertake the work.

The glossary will be found useful to those who adopt the new system in defining specifically each new term, particularly the magmatic names which appear for the most part only in the tables of the five classes where it requires some consideration to frame their definitions Their full value will be appreciated when they are studied in connection with the collection of some thousands of rock analyses made within the past fifteen years, which has been prepared by Henry S. Washington, and will be published shortly.

It is hoped that the present publication will contribute to the better understanding of the development of petrography, and to a fuller appreciation of its defects and needs, and will point out a way along which substantial advancement may be made in the future.

THE AUTHORS.

SEPTEMBER 12, 1902.

# AN INTRODUCTORY REVIEW OF THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY

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# PART I.

## INTRODUCTION.

THE systematic and descriptive science of rocks — petrography — is a product of the nineteenth century. One hundred years ago the distinction had not yet been drawn between the rock and the geological formation or terrane, and many dense rocks were still included among minerals and described as such. With the discrimination between stratigraphic units and rocks proper the science of petrography became outlined, but did not at first receive a name. For some time after the proper scope of the science was clearly defined its development was rapid, and in certain later periods there have been notable advances, due to the invention of some new method of research or to the stimulation afforded by discoveries in some closely allied branch of science.

For the last thirty years or more research in all directions has added greatly to our knowledge of rocks, through the adaptation of the microscope to their study, improved methods of chemical analysis, and a vast store of accurate field observations of occurrence and relationships. But the systematic part of the science has not kept even pace, and does not adequately express the knowledge of the day. This lagging behind on the part of the classificatory branch of petrography is most natural, and similar conditions have existed in various epochs of the past. It is due partly to the necessity for a thorough consideration of the store of new information concerning rocks before its true bearing upon classification could be correctly appreciated, and partly to prevailing differences of opinion as to the relations of petrography to the broader science of rocks — petrology.[1]

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[1] The terms "petrology" and "petrography" have been so widely used in various senses that the writer wishes to urge an agreement among students of rocks to apply each in future in accordance with the scope implied in its etymology. On this basis

At the present time students in many parts of the world, dissatisfied with existing petrographic systems, are turning their attention to classification, and are attempting to apply the newly acquired knowledge, with or without the aid of theoretical considerations, to the construction of improved systematic arrangements of rocks. In view of this situation it has seemed appropriate to present at this time a review of the development of systematic petrography. An understanding of the steps taken in bringing the science to its present condition must certainly be useful to those who would assist in causing important advances in the future.

In this review no attempt will be made to give a complete historical sketch of petrography, but rather to study in a somewhat critical way the course of development through which the science has passed, to analyze the more important contributions to its advancement, and especially to examine the principles nominally applied in formulating schemes of classification and to test the methods of application as to their logical directness and consistency. From some cause the existing systems are commonly regarded as unsatisfactory and inadequate. and this condition indicates either that the principles of classification have not been wisely chosen or that they have been incorrectly applied.

That the standpoint of the reviewer may be clear, it may be well to state the principles which have guided him in his analysis of systematic propositions :

1. A systematic classification of rocks has for its object the arrangement of all rocks in groups according to a method, producing a regular subordination of parts. While in all classifications the groups must possess certain chosen characters in common, the system is natural or artificial according as the

---

the broad science or treatise of rocks is manifestly *petrology*, and the descriptive, systematic science, leading to the nomenclature of these objects, should be *petrography*. This usage corresponds to the definitions given in the " Lexique Pétrographique " prepared by F. Loewinson-Lessing, with the co-operation of many other petrographers, published in the *Compte Rendu of the Eighth International Congress of Geologists* (Paris).

groups express community of fundamental, important characteristics, or of comparatively unimportant properties, chosen for convenience only.

It is commonly admitted that rocks are incapable of truly natural classification, but that the nearest possible approach to a natural system is to be desired. It is, therefore, important to scrutinize systematic propositions to see if their factors of classification have a fundamental connection, making the sequence of divisions natural in desirable degree. Each factor applied should have important natural relations to those preceding and following it in construction of the system. The writer thus believes that the classification of systematic petrography should be a *hierarchical classification*, in distinction to the *cross-classification* necessary in petrology.

2. A systematic classification must be logical in construction. Whatever principles or criteria the architect of a system may adopt, he must be logically consequent and consistent in their application, else his structure is weak, and must fall.

3. It is unscientific to use an assumption which is known to be untrue as a basis of classification.

4. An adequate system of petrography must be stable and comprehensive. In order to fulfil these requirements it must be based upon knowledge, not upon theory or hypothesis; it must be created for *all rocks*, known or unknown, of the characters now understood; its framework must be capable of change in detail without injury to the structure as a whole.

5. The use of ignorance concerning the constitution of some rocks as a factor for their classification is no longer permissible.

If, in the comments to be made upon various systems, it appears to the reader that those of the present day are more severely criticised by the writer than those of earlier periods, it must be remembered that such a discrimination is natural and just. With greater knowledge of rocks, and with the experience of earlier systematists to guide him, the petrographer of the present day should be able to present a classification freer from defects than any proposed by his predecessors. It is the writer's aim to avoid all personal animus in discussion of the existing systems of classification.

Petrography may be concisely defined as the systematic classification of rocks. But if the principal handbooks of today be referred to, it will be found that it is a matter of supposed mutual understanding, rather than of precise statement, as to what constitutes a rock. It is commonly said that rocks are masses of geological importance in the constitution of the earth, but no very serious attempt is made to define what is of importance, or to discuss what treatment shall be given to substances excluded under such a definition. For the purposes of this review, it will be sufficient to define rocks as the *substances constituting* masses of geological importance, recognizing that geological units of mass are not necessarily units in constitution, and may change in material character from place to place. It is the task of petrography to furnish a systematic arrangement of these natural objects and a corresponding nomenclature. The geologist may wish to consider rocks from many different standpoints, each requiring a more or less special grouping and appropriate terms to express the observed or assumed relationships, and such groupings may be apart from systematic petrography.

## VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

The category of rocks as understood today is somewhat different from the categories conceived to be the subject-matter of petrography in various epochs of the past. The early history of petrography is therefore in large degree a history of the differentiation of the sciences dealing with various categories of the mineral kingdom — mineralogy, stratigraphic geology, and petrography. But while a complete review of the subject must note the origin and application of the ideas by which this differentiation was brought about, it is more particularly the object of this retrospect to trace the development of classification, beginning with the time when it was first sought to distinguish a group of objects even approximately corresponding to rocks as at present understood. A brief consideration of the earlier stages is, however, necessary to a clear understanding of the conditions existing in the first decade of this century.

*Linnæus.*—Certain gems and ornamental stones were known to the ancients by names which they bear to this day; but no attempted classification of the mineral kingdom prior to the time of Linnæus, in the middle of the eighteenth century, need be considered at this time, nor is the system of Linnæus of much importance except for the framework of the classification he proposed for the mineral kingdom, the same which he applied with so much greater success to the organic world. It has been said of Linnæus that he had a talent amounting to a genius for the arrangement of natural objects according to system; that "He found biology a chaos; he left it a cosmos." But he extended his *Systema Naturæ* to cover the inorganic world from a logical desire to reorganize the entire field of natural history, rather than from an intelligent knowledge of rocks and minerals.

In the Linnæan system the first grand division of the mineral kingdom is into Petræ, Mineræ, and Fossilia ; but an examination of the substances arranged under these heads shows that the system expresses great ignorance as to the character and relations of many objects classified. Doubtless the followers of Linnæus, who were many and enthusiastic, were stimulated to much research as to the character of rocks and minerals, in their efforts to arrange them within the system of their master; but the most visible effect of the Linnæan system was to furnish a theme for controversial debate and argument for a century to come. The attempt to force inorganic substances into the same scheme of species, genera, etc., provided for plants and animals was warmly advocated on the one hand, and as fervently denounced on the other.

*Development of mineralogy.*—The latter half of the eighteenth century witnessed great advances in knowledge concerning the materials of the earth's crust, and toward its close there began to crystallize out of that knowledge the three sciences of mineralogy, geognosy, and petrography, although the latter was long unnamed.

With more and more accurate information as to the constant chemical composition of minerals, and under the influence of Haüy's brilliant conception of molecular structure and crystal form as attributes of these substances, mineralogy rapidly advanced to its place as a definite branch of science. Its subject-matter grew more and more homogeneous by a process of exclusion, as it became clear that many composite or impure substances had been erroneously classified with minerals. But the mineralogist of this period of development had little interest in and paid little attention to the heterogeneous aggregate of objects rejected from his category. Nevertheless mineralogists considered rocks as so plainly forming an appendix to mineralogy that they set up schemes for their classification based almost wholly upon mineral composition.

*Foundations of petrography.*— While mineralogy was thus developing on definite lines, the students of the mineral masses observed to have wide distribution in the earth were building up a vastly more complex science. By the careful researches of Pallas, de Saussure, von Buch, von Humboldt, Werner, Smith, Macculloch, and many others, the generalizations upon which stratigraphic geology is based were being formulated. The facts of an order in the superposition of strata were established in several localities and the genius of Werner was devoted to the framing of hypotheses explaining the observations made and providing for the extension of generalizations to the rock masses of the globe.

The foundations of petrography were laid in this period, the term rock (*roche*, *Gestein*) was frequently employed, and works termed classifications of rocks were published before the nineteenth century began. Thus in 1787 appeared Karl Haidinger's *Systematische Eintheilung der Gebirgsarten* (Vienna) and A. G. Werner's *Kurze Classification und Beschreibung der verschiedenen Gebirgsarten* (Dresden). The former essay, though awarded a prize by the St. Petersburg Academy of Sciences, appears based upon a superficial knowledge of rock masses when compared with the Wernerian arrangement. In these and other contemporaneous systems it is plain that the geological formation was not distinguished from the rock, as we now use these terms, and hence there was no true petrographical scheme at this time.

*Werner's classification of rock formations.*—Werner devoted much careful study to the mineral composition and general characteristics of rocks, and often described them in appropriate and precise terms. He distinguished between *simple* and *compound* rocks, and recognized that in many cases certain minerals were to be considered as *accessory* as compared with other *essential* constituents. Perhaps more than any other geologist he laid the foundations of *descriptive* petrography, but his systematic arrangement was so predominantly devoted to expressing a supposed order of superposition of rocks in the earth that it was rather a crude stratigraphic scheme than a classification of rocks which he presented. This will be clear from the outline given below.

Werner applied the term "formation" to masses of a certain character originating under certain conditions and perhaps recurring at various times in the history of the earth. Formations were grouped according to the great periods of their origin. He distinguished:

1. Primitive formations (*Das Urgebirge*): Under this head are found granite, gneiss, mica schist, clay slate, limestone, quartzite, porphyry, pitchstone, serpentine, and many other formations.

2. Transition formations (*Das Uebergangsgebirge*): Here were placed clay slate, graywacke, greenstone, gypsum, etc. The oldest fossils were supposed to occur in these rocks.

3. Stratified formations (*Das Flötzgebirge*): In this division are found sandstone, stone coal, marl, rock salt, various limestones, chalk, basalt, amygdaloid, and other formations.

4. Alluvial formations (*Das aufgeschwemmte Gebirge*): Here occur sand, clay, gravel, etc.

5. Volcanic rocks (*Vulkanische Gesteine*): This includes only lavas and ejectamenta of volcanoes, with several pseudovolcanic substances.[1]

The great majority of igneous and metamorphic rocks, as we now term them, were believed by Werner to be of aqueous origin, and were treated as such. In Werner's mineralogical system many rocks also found a place, as appears in von Kobell's statement of his system as it was in 1798. For example, under the clay family (*Thongeschlecht*) are included, among others, pitchstone, clay slate, basalt, wacke, clinkstone, lava, and pumice.[2]

### DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

At the beginning of the century, then, the attempts at the systematic classification of rocks were progressing on two very different lines. On the one hand the mineralogist, treating rocks as an appendage to mineralogy, was arranging them primarily by their mineral constitution, as far as he could determine it, and was for the most part uninfluenced by considerations of geologic origin or occurrence. His system was founded upon the most obvious characteristics of the objects in question.

On the other hand, the geologist was hampered by his efforts to arrange in one system geological terranes (formations) and rocks proper. He could not logically apply any criterion throughout the system, and was most inclined to use geological occurrence and theoretical considerations of origin.

The geologist's early classifications of rocks were naturally more complicated and less logically and consistently carried out than the schemes of mineralogists, and were correspondingly less satisfactory. But no classification of this period could have been really adequate, because the chemical and mineralogical

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[1] This general statement of Werner's elementary system I have taken principally from A. VON ZITTEL'S *Geschichte der Geologie und Paleontologie*, 1899, p. 89.

[2] F. VON KOBELL, *Geschichte der Mineralogie*, 1864, p. 165.

compositions, as well as the origin, of many rocks were unknown, and only modern methods of research have permitted the assignment of a large number of types to their proper relationships.

*Abbé R. J. Haüy.*—The first systematic arrangements of rocks to be of much importance to the science of petrography as now understood were evolved in Paris, and the controlling idea of these systems has dominated French petrography for a century, and is evident in all systems to some extent.

The Abbé R. J. Haüy was professor of mineralogy at the Museum of Natural History in Paris and in charge of its great cabinet of minerals. As already mentioned, his conception of molecular structure and its relation to crystal form had placed mineralogy within its proper sphere. In 1801 he published the first edition of his classic work "*Traité de minéralogie,*" in four octavo volumes, with a fifth of quarto-size containing eighty-seven plates, filled for the most part with figures of crystals. This treatise is evidence at once of the advanced state of mineralogy and of the non-existence of anything worthy of being termed a science of rocks, in France, at this time. The quarto-volume of the *Traité* contains a tabular view of Haüy's "Distribution Méthodique des Minéraux." To this elaborate system of minerals are added two short appendices presenting an arrangement of rocks. One is headed "Agrégats des différentes substances minérales," the other, "Produits des Volcans." That the arrangement of rocks had not received much thought from Haüy at this time is clear from the imperfect scheme presented and from the fact that it was not until 1811 that Haüy addressed a letter to Leonhardt's *Taschenbuch für Mineralogie,* saying that he had conceived the idea of classifying rocks mineralogically ("J'ai conçu l'idée de classer cette suite (des roches) minéralogiquement").

Haüy was not a geologist, and his system must be judged in the light of the circumstances under which it was constructed. These are trenchantly characterized by Lossen in his comment that "the idea of mineralogical classification, of this great contemporary of Werner, did not spring from a wealth of geognostic observations; his letter [above referred to] was not dated from the central plateau of France, from Vesuvius, from the Rhone Valley, or from Predazzo, as were the classic letters of Leopold von Buch at an earlier day, but from the mineralogical cabinet in Paris.[1] Furthermore, the enlargement of the halls allotted to the collections and the consequent rearrangement of the latter was the immediate inspiration of the idea. Haüy's system is therefore characterized by Lossen as cabinet specimen petrography.

The writer does not know whether or not Haüy's revised system was actually published prior to the appearance of the second edition of his *Traité de minéralogie* in 1822. As there presented, it expressed at least ten years' development under the idea announced in 1811. Its principal feature is: a subdivision of rocks into classes, orders, genera, species, varieties, and modifications. Five classes of rocks are distinguished, viz.: (I) Stony and saline; (II) Combustible nonmetallic; (III) Metallic; (IV) Rocks of an igneous origin according to some, aqueous according to others; (V) Volcanic rocks. This grand division is clearly not logical or consistent. General, chemical, and physical properties and mode of origin are all arbitrarily applied. The stony appearance used to produce the first class is recognized as possessed also by the questionable igneous rocks of the fourth class, and is the first factor used for their further subdivision. A "schist inflammable" is included in the first class in spite of the property applied to produce the second class. Except for the class of metallic substances Haüy's category of rocks is similar to that now recognized as the subject-matter of petrography; that is, he did not include with them geological formations, as did many of his contemporaries.

The inconsequent construction of this system appears also in the factors used to produce three orders under the first class,

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[1] K. A. Lossen. "Über die Anforderungen der Geologie an die petrographische Systematik." *Jahrbuch der königl. preuss. geolog. Landesanstalt und Bergakademie*, 1883.

viz.: (I) Phanerogenous ("phanerogène"); (II) Adelogenous ("adélogène"); (III) Conglomerate. The rocks of the first order are made up of definite mineral species, and their composition is apparent. The composition of those of the second order is not apparent to the naked eye, and it is assumed that portions of them do not belong to mineral species. Further, it is stated that some of them are clastic; but why these are not placed in the third order, which is defined as containing rocks composed of cemented particles of older rocks, is not discussed.

The "cabinet petrography" of the mineralogist, as Lossen characterized it, is still more evident in the formation of genera, which in the first class, embracing the largest number of rocks, are named after minerals. The first genus is Feldspar, including not only rocks consisting mainly of feldspar, but also granite, syenite, pegmatite, protogine, gneiss, etc. Similarly, diorite is a species under the genus Amphibole. Haüy's system has always been criticised as giving entirely undue weight to certain minerals; but unnatural as is his scheme in that respect we have the same idea with us today, although it is no more logical now than it was a hundred years ago.

The criteria used in subdividing genera and species in Haüy's scheme are mainly those deemed of *primary* importance by later authorities. The *simple* and the *composite* are the leading heads under the genus, and structure is used to form varieties or modifications under the species.

*John Pinkerton, 1811.*—In 1811 there appeared in London a pretentious work of 1200 pages entitled: *Petralogy, a Treatise on Rocks*, by John Pinkerton, an Englishman. The author was an eccentric character, whose claim to renown rests rather on his historical researches than on his *Petralogy*, for he clearly had little conception of the objects under discussion in that work. The greater part of Pinkerton's energy was directed to a quaint and prolix argument against the tendency of the time to classify mineral substances in the same manner as animals and plants. His *bête noire* was the mineral *species*, for he insisted that the essential element of the species in the animal or vegetable kingdom was its power to "produce a similar progeny."

> Dr. Jameson tells us [remarks Pinkerton] that there is in fact but *one* species in mineralogy, namely, the globe; but even this may be doubted till it shall have produced another, at least as round and as wicked.

Admitting as appropriate the fundamental division of natural history into three kingdoms, the animal, vegetable, and mineral, Pinkerton ingeniously draws a distinction.

> In the two former [he remarks] the kingdom consists of living subjects who, of course, may be well considered as divided into classes, orders, genera, and species; but in the mineral kingdom the territory alone constitutes the subject of discussion.
>
> But the very term mineral kingdom may of itself lead to a new and more proper nomenclature; for as a kingdom may be regarded as either vivified with animal and vegetable life, or as an inert tract of country, with certain geographical, chorographical, and topographical divisions; so the latter point of view can alone apply to mineralogy, while the former belongs to zoölogy and botany.
>
> What is more usual than the division of a kingdom into provinces, districts, domains, etc.? I would propose, therefore, in the present advanced state of the science, that the mineral kingdom be considered as divided into three Provinces:
>
> 1. Petralogy, or the knowledge of rocks, or stones which occur in large masses.
> 2. Lithology, the knowledge of gems and small stones.
> 3. Metallogy, or the knowledge of metals.
>
> Petralogy, a Province of mineralogy [is then] divided into twelve *Domains*; of which the first six, being distinguished by the substances themselves, may be called *substantial*; while the remaining six, being distinguished by circumstances or accidences of various kinds, may be called *circumstantial* or *accidential*; but this last division is of little moment.

The six "substantial" domains of Pinkerton are:

1. The Siderous, in which iron predominates.
2. The Siliceous.
3. The Argillaceous.
4. The Magnesian.
5. The Calcareous.
6. The Carbonaceous.

The "accidential" domains are:

7. The Composite.

8. The Diamictonic, "in which substances are mingled."
9. The Anomalous, "or those which contradict the common order of nature."
10. The Transilient.
11. The Decomposed.
12. The Volcanic.

This outline will indicate sufficiently that the *Petralogy* has no real importance to the present review. Pinkerton does not appear to have been taken seriously by his contemporaries, as there is little or no reference to his elaborate system in succeeding publications of his countrymen.

*Alexandre Brongniart, 1813.*—In 1813 Alexandre Brongniart[1] published a *Classification minéralogique des roches mélangées.* The writer has not seen the original, but von Leonhard gives a tabular view of the scheme proposed by Brongniart, which shows it to have been crude, and not worthy of special discussion here, because of the much more elaborate and mature work by this author issued a few years later, to which some space must be given. But comparatively crude as this outline was, it gave much evidence of the logical mind of its author.

*P. L. A. Cordier, 1815.*—Contemporaneously with the constructive labors of Haüy and Brongniart, another French master was also struggling with the same problem. It is to the painstaking researches of P. L. A. Cordier that we owe the first great step in deciphering the composition of volcanic and other rocks of such fine grain that their constituents could not be recognized by the simple methods of examination then in use. He instituted chemical, microscopical, and mechanical researches of much ingenuity, and arrived thus early at the conclusion that volcanic rocks were made up of known minerals in microscopic crystals or grains, and of glass, which he believed contained the same elements. In 1815 Cordier presented to the Academy of Science in Paris the results of his investigations in an important work upon the substances composing volcanic rocks.[2] The

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[1] *Journal des Mines*, Vol. XXXIV.

[2] P. LOUIS CORDIER, "Mémoire sur les substances minérales dites *en masse*," etc., followed by "Distribution méthodique des substances volcaniques dites *en masse*,"

classification of volcanic rocks accompanying his memoir was limited to the few surface lavas then known and the tuffs and ashes. He had the idea that either feldspar or pyroxene predominated in all cases, and hence the first division was into feldspathic and pyroxenic rocks. Texture was the main property applied for further subdivision.

*John Macculloch, 1822.*—The third decade of the century witnessed the publication of several important essays in rock classification. The first of these was by John Macculloch, and was entitled *Geological Classification of Rocks, with Descriptive Synopses, Comprising the Elements of Practical Geology*, issued in London, 1822. Macculloch's work is called "a classification of rocks," but it is really a classification of rock formations, as we should now express it. It is an attempt at stratigraphic geology without recourse to fossils. Its foundation was a knowledge, which was very thorough for the time, of the rocks of a limited area, and the assumption that the same rocks must, in general, occur in all parts of the world in the same sequence and relations as in the British Isles. In discussing the basis of his scheme he says:

> In considering the different plans on which a classification of rocks might be constructed, he (the author) was, without hesitation, led to adopt one founded on the geological relations and positions of rocks in nature . . . . the basis of the arrangement is virtually the same as that adopted by Werner.

Macculloch thought that all rocks might be placed in a few groups, distinguished by certain prevailing mineral characters.

> It will be further seen [he says] that these different groups are also in a great measure distinguished in nature by certain general or geological relations, more or less constant and perfect.

The arrangements according to mineral characters and geological relations were believed to coincide.

The attempt to use fossils as criteria of the age of rock formations, which was then being made by the Germans, did not appeal to Macculloch. He is said to have been jealous of the

*Journal de Physique*, 1815–1816. Both memoir and table of classification were reprinted by D'Orbigny in 1868, in his work *Description des roches*, etc., which gave the system of Cordier as elaborated at the time of his death, in 1861.

rapidly developing science of palæontology. In his opinion fossils were not well enough known, as to their kinds or their distribution, to be used as factors in classifying rocks as to their geological position. He says, however, that he looks forward to the time "when a system of organic mineralogy will be formed."

With regard to his system Macculloch remarks:

> The classification is simple; all rocks being referred to a primary and a secondary class, and a smaller division being formed of those which are found in both. The substances which cannot be referred to the latter class, from their more recent origin are considered separately in an *appendix;* and a similar expedient is adopted for the volcanic rocks.

"Primary" means to Macculloch anterior in date to the secondary; and "secondary" means later than the primary. Each class is divided into two divisions, the *Stratified* and the *Unstratified.* "As these subdivisions," remarks the author, "have not yet been introduced into any of the arrangements of rocks, they will each require some explanation."

The result of Macculloch's scheme is expressed in the following tabular arrangement of rocks:

### PRIMARY CLASS.

*Unstratified.*

Granite.

*Stratified.*

Gneiss.
Micaceous schist.
Chlorite schist.
Talcose schist.
Hornblende schist.
Actinolite schist.
Quartz rock.
Red sandstone.
Argillaceous schist.
Diallage rock.
Limestone.
Serpentine.
Compact feldspar.

### SECONDARY CLASS.

*Stratified.*

Lowest (red) sandstone,
Superior sandstones.
Limestone.
Shales.

*Unstratified.*

Overlying (and venous) rocks.
Pitchstone.

### OCCASIONAL ROCKS.

Jasper.
Siliceous schist.
Chert.
Gypsum.
Conglomerate rocks.
Veinstones.

### *Appendix.*

Volcanic rocks.
Clay, marl, sand.
Coal.
Alluvia.
Lignite.
Peat.

If we examine this table, it is seen that Macculloch was not able to carry out consistently the application of the factors adopted. This is most conspicuously the case with the "overlying (and venous) rocks" placed in the unstratified division of the secondary class. These overlying rocks were, in fact, recognized as later than the secondary rocks in many cases. They are mainly what we should call intrusive igneous rocks, found cutting other rocks, and of the real age of which Macculloch confessed that he had little evidence. He was ignorant of the composition of aphanitic or felsitic rocks, and they receive no consistent treatment at his hands.

Macculloch is credited with having been a keen observer and with having made truly great contributions to stratigraphic geology. But he does not appear to have conceived of the distinction between a geological formation and a rock. There are in his book many phrases, such as the title of the work itself, and statements scattered through it, which are couched in the language of today, but have very different significance at this time. It is interesting to apply many of his remarks concerning the condition of the systematic science of rocks, as understood by him, to the petrography of today.

*Karl Cæsar von Leonhard, 1823.*—In 1823 appeared a truly epoch-making work, the *Charakteristik der Felsarten* by Karl Cæsar von Leonhard, professor at the University of Heidelberg. This is, in fact, the first fairly consistent treatise upon rocks. It is founded upon an exceptionally accurate knowledge of the objects classified, and with advanced ideas as to the true relations between geognosy proper and the descriptive science of rocks. Yet von Leonhard did not give his science a name, and presents it as a part of geognosy.

Von Leonhard says that his object is to present all facts bearing upon the *character* of rocks, an aim expressed in his chosen title. He points out that a discussion of the stratigraphic relations of rocks must be preceded by an accurate statement of their nature. Rocks are defined as the mineral masses of more or less considerable extent in the crust of the earth. It is recognized that, from the standpoint of geognosy proper, only those masses can be considered important the extent of which is so considerable that general laws as to their relations and distribution may be discerned. Yet it is pointed out that there are other masses of subordinate or abnormal occurrence which may have a wide distribution, though occupying no position peculiar to themselves, and that these masses are important when arranged by their characteristics. Stratigraphic geology and petrography are thus fairly outlined, though no definite proposal for their separation is made.

The classification presented by von Leonhard has many features which are preserved in modified form in the German systems of today. Like all early systems, however, the primary division is arbitrary, and drawn upon no definitely stated principle. Four divisions are established: (1) Heterogeneous rocks, (2) Homogeneous rocks, (3) Fragmental rocks, (4) Loose rocks, while coals are placed in an *appendix*. For subdivision, structure is used as the basis, the granular, schistose, porphyritic, dense, and glassy groups being established in some of the main divisions. These terms are used with nearly the meaning we now attach to them. The principal anomalies of association in the arrangement arise from the throwing together of igneous and sedimentary rocks in certain groups, and from the inconsequent way in which von Leonhard met the difficulty of dealing with the more or less dense rocks, the composition of which could not then be ascertained. These were mainly of igneous origin, and not stratigraphic units, and there was no proper place for them in the system. They were treated as a group by themselves under the Homogeneous rocks, with the heading, "Rocks (apparently homogeneous) which are not to be regarded as minerals" ("Nicht als Glieder oryktognostischer Gattungen zu betrachtende—scheinbar gleichartige—Gesteine"). Here we find trachyte, aphanite, serpentine, basalt, pitchstone, obsidian, and various schists. Von Leonhard realized more or less clearly that most of these rocks would some day be found to be complex in character, and he therefore appreciated that his treatment of them was a makeshift. Twelve years later, in his *Lehrbuch der Geognosie und Geologie*, he raised the *apparently homogeneous* rocks to an equal rank with the heterogeneous and homogeneous divisions.

Von Leonhard was unquestionably the foremost petrographer of his day, sharing with Alexandre Brongniart the honor of first placing the classification of rocks upon a firm basis as a systematic science. He had been called to Heidelberg but a few years before this work was issued, finding there perhaps the largest collection of rocks then in existence. He had also visited Paris and studied the great collection of the Museum of Natural History as arranged by Haüy. Von Leonhard also belonged to the group of German geologists who, with Smith and Macculloch in England, and a few elsewhere, were engaged in placing stratigraphic geology upon a sure foundation. He did not himself develop the distinction, clearly foreshadowed in his work, between the geological formation and the rock.

A critical examination of the system contained in the *Charakteristik* shows that von Leonhard actually applied as his first criterion the distinction between massive and clastic rocks, as we should express it, though he may not have realized it. Next he applied the idea of homogeneity and its opposite. But the notable feature is the prominence given to structure and the close approximation of some of his definitions to ones in current use. It was the first time structure was assigned so prominent a rôle in a system of rocks. Mineral composition followed structure, and was applied quite reasonably.

The system of von Leonhard is specially noteworthy as the work of a German, for in it he breaks away from the influence of the Wernerian school. This was doubtless to some extent the result of a visit to Paris, but while building upon the characteristics of rocks he did not give to mineral composition the completely dominating place which it held in the French systems. Von Leonhard rejects the biological framework of classes, orders, genera, and species as quite inapplicable to rocks, since they lack individuality.

*Alexandre Brongniart, 1827.*—The *Classification et charactères minéralogiques des roches homogènes et hétérogènes*, by Alexandre Brongniart, published in 1827, marks the next important step in the development of petrography. This admirable little book of only 144 pages contrasts markedly with other voluminous works of its period. It is concise in statement, and presents a clearly conceived and logically worked out system.

In the introduction we find minerals, rocks, and geological terranes distinguished and defined. *Minerals* are species or varieties determined by the laws of mineralogy; *rocks* are the same substances considered in their masses and as entering into the structure of the globe; *terranes* are assemblages of several rocks, considered as having been formed at about the same epoch. Brongniart pointed out that there were two ways of looking at rocks—as to their composition, and as to their occurrence. He held that geognosy was not strictly a classification of rocks; that to arrange rocks by occurrence and describe them in that order involved many digressions from the discussion of relationships; that rocks formed at different times must then be referred to as many times as they occurred; that the same name would be given to different substances formed at the same time; and, finally, that classification by occurrence involved the use of hypotheses where knowledge was lacking. All these troubles should be avoided, in his opinion, by classifying and naming rocks upon mineralogical composition and independently of occurrence. The treatment from the latter standpoint could then follow naturally.

The system of Brongniart is a mineralogical classification with the aid of the exterior characters. His divisions are styled classes, orders, genera, and species. There are but two classes, viz.: (1) "Roches homogènes ou simples;" (2) "Roches hétérogènes ou composées." In this respect Brongniart is more logical than von Leonhard. The *Homogeneous rocks* are defined as those that *appear to be so* to the naked eye. There are two orders under the class of *Homogeneous rocks*, namely: (1) "Roches phanérogènes (of distinct known mineral species); (2) "Roches adélogènes" (of unrecognizable constitution). This division is logical enough, but it is based on a criterion of primary value which is clearly applicable to *all* rocks. The result is that under Homogeneous rocks are included, in the second order, a number of substances, including clays, dense schists, trap, basalt, and other igneous rocks, of really heterogeneous character.

The Heterogeneous rocks are also divided into two orders: (1) "Les roches de cristallisation; (2) Les roches d'agrégation." This distinction really introduces the factor of conditions of origin, which fact Brongniart seemingly did not recognize, as he makes no comment upon it.

When it comes to finer subdivision we find that this system is almost purely mineralogical, as its title claims. Structure is relegated to a very subordinate rôle, wherever it is convenient to apply it.

*Systems of von Leonhard and Brongniart compared.*—If we now review the construction of the systems proposed by von Leonhard and Brongniart, which may be taken as the real starting point of systematic petrography, we find that both resorted at once to an expedient which expressed the fact that in their day the composition of many rocks was unknown. And the principal inconsistencies of the two arrangements came from their treatment of the aphanitic rocks of all kinds throughout the schemes. But we must admit that these substances could not be correctly classified by composition so long as their character was so nearly unknown.

Both these masters relied mainly on *mineral composition*, but von Leonhard advanced *structure* also to a prominent place Both declared that the system and nomenclature of rocks should be founded upon *characteristics*, and that the various treatments rocks must further receive from the geologist would be facilitated rather than retarded by such an arrangement. Brongniart made a suggestion, apparently unconsciously, in subdividing Heterogeneous rocks, that geological conditions of origin might serve as a practical basis in classification; but he made only limited application of that factor, and does not appear to have grasped the broader meaning of his own proposition.

After von Leonhard and Brongniart had placed petrography upon a firm basis, no great advance was made in the systematic part of the science until the middle of the century. The cause of the unsatisfactory elements in the early schemes was recognized to lie in the ignorance concerning the character of many rocks, and a large number of investigators devoted themselves to the study of the composition of rocks on the one hand and to their geological relations on the other. While the object of this review is to trace the application of principles or of knowledge in classification rather than to follow the course of investigation, it is necessary to refer briefly to the studies made during the second quarter of the century, noting the use of new knowledge in system.

*Investigations into the chemical composition of rocks.*—Among the characters of rocks not taken into appropriate account in the first systems, by far the most important is *chemical composition*. But from the beginnings under Cordier more and more attention was paid to chemical investigation, until other things became quite subordinate. First, qualitative test was applied, then partial analysis, and finally bulk analysis. Chemical research was naturally applied with most valuable results to the denser rocks, chiefly of igneous origin, and in this way, with ever-extending field investigation, it was found that these substances were vastly more complex, more varied in character, and much more common than had been supposed. From these causes the petrography of igneous rocks grew to be the principal part of the science instead of being relegated to an "appendix," as had been done at an earlier day.

The chemical analysis of igneous rocks was mainly directed to a determination of their mineral constituents and to the question as to whether the various oxides were present in simple or constant proportions or not. For the latter inquiry the ratio of the oxygen contained in the silica to that of the bases, taken together or in groups, was calculated and comparisons instituted. G. Bischof set up as a means of comparison the so-called "oxygen quotient," obtained by dividing the total oxygen of the bases by that of the silica, as shown in the analysis of any given rock. That the faulty analyses of the time could not in any case have yielded trustworthy evidence of stoichiometric or constant proportions of the constituents is now clear; but even with the imperfect analyses the complexities of the problem were such as to lead nearly all chemical students of rocks to abandon attempts to deduce chemical formulæ or simple ratios for them.

For many years chemical investigations were necessary in determining the approximate mineral composition of many rocks, and important discoveries were undoubtedly made; but it is pathetic to recall the years spent in hard labor by many of the foremost men of their time in endeavoring to work out the mineral composition of fine-grained or aphanitic rocks from incorrect or inadequate bulk analyses, and with very imperfect knowledge of the constitution of some rock-making minerals. Abich, Bunsen, von Waltershausen, Bischof, Scheerer, Roth, Streng, Delesse, Haughton, and many others devoted much time to this research without what appears to us, at this time, to have been commensurate results.

*Classification by feldspars.*—The principal effect of this chemical work upon petrographic classification appears to have been to perpetuate the mistake of giving an undue importance to the feldspars as rock constituents. As different kinds of feldspar were recognized by chemical analysis, largely through the researches of Gustav Rose, a further mistake was made. It was for a time thought that orthoclase (or potash feldspar), albite, oligoclase, labradorite, and anorthite were the only feldspar species entering into rocks, and that they did not occur to any great extent in association. Hence, after setting up a great division of *feldspathic rocks*, the logical method for subdivision was according to the kinds of feldspar present. This was thought to be the more surely a correct principle, since its application seemed to produce groups nearly coinciding with those previously recognized, but less sharply defined.

Perhaps the first to advocate the use of feldspars in this way was Hermann Abich, in 1841.[1] Abich viewed magmas as basic, neutral, or acid silicate solutions of a great range in specific gravity. As the known feldspar series presented also a wide range in silica and in specific gravity, it seemed to him certain that there must be a definite relation between the silica content of a given magma and the feldspar which could crystallize out of it. It therefore seemed to him possible to use the various feldspars for the classification of endogenous (or eruptive) rocks very much as fossil remains were used in sedimentary rocks. For the next twenty-five years a sharp division according to feldspars was advocated, in systems to be reviewed; and it required the application of the theory of isomorphous mixtures to feldspars, the polarizing microscope, and modern methods of mechanical and chemical analysis, to demonstrate the true distribution of feldspars in rocks, and the thoroughly artificial nature of this arrangement.

*Influence of genetic hypotheses.*—The connection of chemical composition of igneous rocks with theories as to the origin of the differences in composition of magmas and the use of the genetic conception in classification forms an interesting chapter in the history of systematic petrography. Yet the application of this genetic idea led at first only to a broad and ill-defined

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[1] H. ABICH, *Geologische Beobachtungen über die vulkanische Erscheinungen und Bildungen in Unter- und Mittel-Italien*, Braunschweig, 1841.

proposition in classification which does not require full discussion in this place. Reference is had to Bunsen's hypothesis of two fundamental magmas—the trachytic and the pyroxenic—mixtures of which were supposed to produce all igneous rocks.[1] From the systematic standpoint Durocher's hypothesis had the same result, though differing somewhat from Bunsen's in the physical origin of the magmas. Durocher (1857) carried out a chemical division of igneous rocks on his hypothesis, forming the *acid*, *hybrid*, and *basic* groups.[2] Th. Kjerulf[3] (1857) proposed four chemical groups: *acid*, *neutral*, *basic*, and *ultra-basic*, and various authors recognized the grand division of *acid* and *basic*. Such divisions, when closely connected with hypotheses, have had more influence upon the geologist than upon the systematic petrographer; for it was quickly found that, although the fundamental idea might be near the truth, the theory was too imperfect (or narrow) to explain the observed range in chemical composition of igneous magmas. The broad chemical distinction, considered merely as a recognition of the observed range in composition of rocks, was not given sufficient precision to be of much value in system.

*Geological classifications.*—During these years of patient research, especially into the composition of igneous rocks, geologists were making important contributions to the broader phases of classification. As a knowledge of occurrence, relation, and modes of formation of rocks increased many different factors were tested as to their applicability to the formation of systematic arrangements. Soon the numerous geological standpoints from which rocks might be viewed and classified led to a great many schemes for their arrangement, and much confusion existed. This condition continued until the geologist separated the systematic classification of rocks from various other arrange-

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[1] R. BUNSEN, "Ueber die Processe der vulkanischen Gesteins-bildungen Islands," *Poggendorf's Annalen*, etc., Vol. LXXXIII, 1851, pp. 197–272.

[2] J. DUROCHER, "Essai de pétrologie comparée," etc., *Annales des Mines* (5), Vol. XI, 1857, p. 217.

[3] *Nyt magazin for naturvidenskaberne*, Vol. IX, 1857, p. 294.

ments of which these bodies were found capable. Certain geologists, as, for instance, De la Beche in England, had, at an early day, very clear and logical ideas as to the principles which must control classification. In the third edition of his *Geological Manual*, issued in 1833, is the sentence: "Classifications of rocks should be convenient, suited to the state of science, and as free as possible from a leading theory." In accordance with this principle, De la Beche divided all rocks (including formations) into *stratified* and *unstratified*, "independent of the theoretical opinions that may be connected with either of these great classes of rocks." The stratified rocks were then subdivided into "superior or fossiliferous" and "inferior or non-fossiliferous." By this logical division De la Beche at once secured classes or subclasses corresponding well to those now called igneous, metamorphic, and sedimentary.

*Carl Friedrich Naumann, 1850, 1858.*—Without attempting a complete history of the introduction of each factor into classification, we will now consider the system of Carl Friedrich Naumann, the great Saxon geologist, as of much importance in presenting *a new mode of treatment*. The first edition of his *Lehrbuch der Geognosie* appeared in 1850, the second in 1858. Naumann was a great systematist; he viewed rocks from many standpoints, and from each constructed a peculiar scheme of treatment. Thus one section of the *Geognosie* was called "Petrographie oder Gesteinslehre," defined farther as a branch of "Chthonographie oder die Geognosie im engeren Sinne des Worts." This is the first use of *petrography* of which I have knowledge. It is used in the sense of petrology, as the latter term is now commonly applied in America.

Naumann not only gave the comprehensive science of rocks a special name, but he established within it six divisions, namely:

*A*. Hylology, a discussion of the constituents of rocks.
*B*. Histology, on texture and structure of rocks.

*C.* Morphology, a classification of forms of occurrence.
*D.* Synopsis, or the systematic descriptive science.
*E.* Petrogeny, a discussion of the genesis of rocks.
*F.* Allo-osology, the science of the alteration of rocks.

Under this elaborate framework rocks were grouped in many ways. They were considered as minerogenous, zoögenous, or phytogenous, according to origin of materials; as crystalline, clastic, dialytic, or amorphous, depending on character of the constituent grains; as simple or composite; in another view as phanomeric or cryptomeric, and so on.

But when it came to the systematic arrangement of his "Synopsis" Naumann was at sea. He himself called it an *attempt* at a grouping of rocks—"Ein Versuch einer Gruppirung der Gesteine"—and plunged without discussion of principles into the description of rocks under a scheme of classes, orders, families, and lesser divisions.

In the first edition of the *Lehrbuch*, Naumann divided all rocks into three classes, namely: (1) Crystalline rocks; (2) Clastic rocks; (3) Rocks which are neither crystalline nor clastic.

It was explained that the groups of amorphous, zoögenous, and phytogenous rocks are scarcely co-ordinate in importance with the crystalline and clastic divisions, so they were united in the third composite class. In the descriptions of the Synopsis, however, the amorphous (hyaline and porodine) rocks were considered in connection with the rocks of the other two classes to which they are related in composition.

In the second edition but two classes were recognized, embracing all rocks: (1) Protogenous (original); (2) Deuterogenous (derived). Naumann gave no discussion of the basis upon which he made the change.

In both editions Naumann leaves the manner of subdividing classes to the reader to make out for himself. In the class of original rocks are six orders, viz.: (1) Ice, (2) Haloid rocks, (3) Quartz rocks, (4) Silicates, (5) Ores, (6) Coal. Families are produced within these orders by mineral composition. Structure, texture, and other properties are occasionally used for minor unnamed divisions. After the elaborate preparation for this arrangement, it must be confessed that Naumann failed utterly to produce a system worthy of the name. No logical and consequent application of principles can be found in his Synopsis.

The great value of Naumann's work lies in the clear setting forth of the scope of the *general science* of rocks, independently of their formal or historical relations to the earth. He outlined the divisions under the broad science, and showed the proper position of the purely systematic and descriptive branch. He illustrated clearly how many arrangements or groupings of rocks are natural and necessary from the geologist's standpoint, and evidently understood that he could not introduce all these considerations into the construction of one system of classification.

In the development of petrographical system, Naumann's analysis of the broad science was of great importance. For many years the primary classification of rocks, leading to an arrangement for purposes of description, followed some of the various ways set forth by him. And even at the present day we find H. Credner, a successor of Naumann in the university at Leipzig, presenting rock descriptions in his well-known *Elemente der Geologie* under a framework very similar to that of the *Lehrbuch der Geognosie*. Whatever the choice of criteria adopted by individuals from among the alternatives presented by Naumann, very similar, if not identical, major divisions were formed.

*Bernhard von Cotta, 1855, 1862.*—Almost contemporaneously with Naumann's *Geognosie* appeared several other treatises on rocks by German authors of note. *Die Gesteinslehre*, by Bernhard von Cotta, was first published in 1855, and its second edition in 1862, the latter being translated into English and serving for years as a standard work.

The first edition of the *Gesteinslehre* professes to be merely a description of rocks, and the arrangement or order in which the various kinds are presented is stated to be one of convenience only. Von Cotta's point of view was that, as rocks are simply aggregates of mineral particles, one kind grading into another, and as they are of different modes of origin, there can be no species comparable to those of plants, animals, or minerals, and hence a classification, properly speaking, is an impossibility. Reviewing the various characters of rocks as to their application in nomenclature and description, this author touches on some fundamental points with noteworthy discrimination. This is particularly true with regard to his remarks on the availability of texture for purposes of classification. Noting that it is the most easily distinguished character of rocks, and that it had been used as a primary factor in classification, he pointed out that chemical and mineral composition were more fundamental, and that there was nothing so intrinsically important in texture that differences in that respect should be allowed to separate things otherwise alike.[1] It seemed to him better to name the rock from its mineral composition, and for textural varieties to add expressive terms.

In this first edition of the *Gesteinslehre*, von Cotta introduced no geological factor into his adopted arrangement. He treated all rocks in the following groups, which were purely for convenience:

1. Basaltgesteine.
2. Grünsteine und Melaphyre.
3. Trachyte.
4. Porphyre.
5. Granite und Gneisse.
6. Glimmerschiefer.
7. Thongesteine.
8. Kieselgesteine.
9. Kalksteine und Dolomite.
10. Gypsgesteine.
11. Verschiedene Mineralien als Gesteine.
12. Eisengesteine.
13. Kohlen.
14. Trümmergesteine.

In the second edition of the *Gesteinslehre*, issued in 1862, while still claiming rocks to be incapable of true classification by inherent characters, von Cotta makes a noteworthy advance toward a systematic arrangement by grouping them primarily according to geological mode of origin. As further factors he uses, in certain classes, broad chemical distinctions and form of occurrence. His general scheme is as follows:

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[1] "Genau genommen ist indessen die Textur gar nichts so wesentliches, dass sie veranlassen könnte, wegen ihrer Ungleichheit zwei Gesteine ungleich zu nennen wenn sie übriges gleich sind."—*Gesteinslehre*, p. 22, 1855.

I. Eruptive rocks, probably all originating through consolidation from a molten condition.
  1. Poor in silica, or Basic.
    *a.* Volcanic.
    *b.* Plutonic.
  2. Highly siliceous, or Acid.
    *a.* Volcanic.
    *b.* Plutonic.

II. Metamorphic crystalline schists, probably all derived from sediments, yet resembling eruptive rocks in mineral composition.

III. Sedimentary rocks.
  1. Argillaceous.
  2. Calcareous.
  3. Siliceous.
  4. Tuffs.

To these three clearly defined groups was added an appendix of rare rocks or those of problematic origin. Here were included many quartzose rocks, coals, iron ores, serpentine, etc.

The eruptive rocks were considered as derived from molten magmas; the broad chemical distinction was made with Bunsen's law in mind, but not directly as its expression; the volcanic and plutonic rocks were separated purely on the basis of occurrence; the further subdivision was by general mineral composition, and texture was used as subordinate to it. It is worthy of special note that von Cotta expressly pointed out that geological age was not involved in the distinction between the volcanic rocks and the plutonics. He considered that the older volcanics had been largely removed by erosion, and that the younger plutonics had not yet been laid bare.

*Ferdinand Senft, 1857.*—In 1857 appeared an elaborate work by Ferdinand Senft, with the title (translated) *Classification and Description of Rocks, Founded upon their Mineral Constitution, Chemical Composition, and Structure.*[1] This treatise, which received the Demidoff prize (St. Petersburg), is mainly notable for its elaborate attempt to apply chemical factors in details of classification.

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[1] "Classification und Beschreibung der Felsarten, gegründet auf ihre mineralogische Beschaffenheit, ihre chemische Zusammensetzung und ihre Structur," Breslau, 1857.

In this work Senft gives detailed tables for the determination of rocks, the first of which presents the following general scheme of classification:

A. Inorganic rocks ("Anorganolithe").
  I. Crystalline.
    1. Simple.
    2. Composite.
  II. Clastic.
    *a.* Indurated.
      1. Pseudoclastic.
      2. Hemiclastic.
      3. Holoclastic.
    *b.* Unconsolidated.
      1. Gravel, sand, etc.
      2. Soil ("Erdkrumer").
B. Organic rocks.

Curiously enough Senft's discussion of principles of classification begins with the consideration of the means for subdividing the smallest divisions of this table, which he calls "Classes."

Senft believed that rocks of these classes should be further arranged by their characters. Reviewing these, he points out the great difficulties in so classifying them, owing to the fine grain, variable composition and texture of many kinds. The facts lead him to assert that the main systematic divisions, such as orders, groups, etc., cannot be founded on structure (Gefüge) or other outer habit of the rocks, because the former factor would at once separate similar things, and the latter bring different things together. Mineral composition would be the best basis for arrangement were it not for the fact that, in the fine-grained or aphanitic rocks, chemical tests are necessary to determine the mineral components. As it is, the chemical relation of rocks—and especially of the crystalline—to certain solvents affords the only safe means by which rocks can be classified. This factor of solubility is actually applied to the formation of orders, suborders, and groups under the classes provided by the scheme already outlined. Senft is, however, not fully consistent, for the first division of the class of composite crystalline rocks is on mineral composition, into the two orders: (1) Alabradorites (rocks free from labradorite, generally rich in quartz, and never containing augite); (2) Labradorites (rocks characterized by labradorite and free from quartz and orthoclase). These were subdivided into nine groups, according to the action of hydrochloric or sulphuric acid upon the rocks. For further details of this unique and highly artificial system the reader must be referred to the original work.

*J. Reinhard Blum, 1860.*—Shortly after the treatises of Naumann, von Cotta, and Senft, there was published the *Handbuch der Lithologie oder Gesteinslehre*, by J. Reinhard Blum.[1] This work is but little more than a descriptive handbook, with slight discussion of principles of classification, and in it no original contribution to the systematic science was made. The main divisions of the work are as follows:

I. Crystalline rocks.
  A. Homogeneous.
    *a.* Granular.
    *b.* Schistose.
    *c.* Porphyritic.
  B. Heterogeneous—with three structural divisions.
II. Clastic rocks.
  A. Cemented.
  B. Not cemented.

The further division of crystalline rocks is by mineral composition.

*Justus Roth, 1861.*—Among the students of the chemical composition of igneous rocks none has rendered greater service than Justus Roth, who, in 1861, published his *Gesteinsanalysen, in tabellarischer Übersicht und mit kritischen Erläuterungen.* Upon the basis of nearly a thousand analyses available at that time, Roth undertook to ascertain whether chemical composition gave in itself a practical ground for the classification of igneous rocks. As a basis for comparison of analyses Roth selected the oxygen ratio, *i. e.*, the ratio of the oxygen of the acid radical, $SiO_2$, to that of the bases, RO (including $R_2O$) and $R_2O_3$, and obtained

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[1] *Erlangen*, 1860, pp. 356.

the oxygen quotient (originally proposed by Bischof) by dividing the oxygen of the bases by that of silica.

Comparing all available analyses in this way Roth recognized that no simple chemical relations existed between different rocks, and that chemical formulæ were therefore useless; that rocks of different mineral composition fell in the same chemical division; that chemical and mineral arrangements of rocks could not coincide; that a purely chemical arrangement would separate things closely related on geological and mineralogical grounds; and that a mineralogical arrangement must be connected with structure and texture. In this dilemma Roth chose to arrange igneous rocks primarily by their kinds of feldspar and the presence or absence of quartz. He admits that pyroxene or amphibole might be used in the same way, but considers feldspar much preferable because of its greater abundance and easier determination. The scheme of classification presented by Roth is as follows:

I. Orthoclase rocks (often containing some oligoclase).
  A. With quartz (*i. e.*, more siliceous than orthoclase).
    1. Granite.
    2. Gneiss.
    3. Felsite porphyry.
    4. Liparite.
    5. Syenite.
  B. Without quartz.
    1. Orthoclase porphyry.
    2. Sanidine trachyte.
    3. Sanidine-oligoclase-trachyte.
    4. Phonolite.
    5. Leucitophyre.
II. Oligoclase rocks.
  A. With hornblende.
    1. Diorite.
    2. Porphyrite.
    3. Amphibole andesite.
  B. With augite.
    1. Oligoclase-augite-porphyry.
    2. Melaphyre and spilite.
    3. Pyroxene-andesite.
    4. Nephelinite.
    5. Haüynophyre.
III. Labradorite rocks.
    1. Labradorite-porphyry.
    2. Gabbro.
    3. Hypersthenite.
    4. Diabase.
    5. Dolerite.
    6. Normal pyroxenic rock (Bunsen.)
    7. Basalt.
IV. Anorthite rocks.
  A. With augite — eukrite.
  B. With hornblende.

This arrangement attempts no expression of a relation between chemical and mineral composition; it assumes constant presence of feldspars in some amount in all rocks, and also certain characteristic associations of minerals. It indirectly recognizes structure and geological age as factors in classification. Roth believed that the classification by mineral components outlined certain combinations or associations as central points of notably frequent and widespread occurrence, about which the rocks of other combinations and of comparative rarity must be grouped. While expressing the idea that not only the kind but the amount of various minerals might be considered in a mineral classification, he confined his own adaptation of this idea to the recognition of *essential* and *accessory* constituents, in certain cases, and with no definite plan.

*Th. Scheerer, 1864.*—Shortly after the appearance of Roth's tables of rock analyses, a proposition for the general classification of igneous rocks upon a chemical basis was published by Th. Scheerer.[1] This proposition is notable as representing the views of one of the men who, in the preceding decade, had devoted much time and labor to the bulk analysis of rocks. Unlike Roth, who had come to the belief that no simple and persistent chemical formulæ or ratios could be set up for igneous rocks, Scheerer was convinced that he had found such formulæ, and that all silicate rocks could be referred to nine comparatively simple chemical types.

Upon the basis of earlier investigations of the gneisses of the Saxon Erzgebirge, Scheerer had come to the idea that all of them could be considered as mixtures of three magmas, represented in nearly pure form in three prevalent gneisses of the region, namely: the "Rother Gneiss," "Mittlerer Gneiss," and "Grauer Gneiss," the composition of which might be expressed in simple formulæ, given below. The visit to the Fassathal was made to test the general applicability of this threefold division to other highly siliceous rocks, and to gather from the numerous basic rocks of that region material for chemical

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[1] "Vorläufige Bericht über krystallinische Silikatgesteine des Fassathales und benachbarter Gegenden Südtyrols," *Neues Jahrbuch für Mineralogie*, etc., 1864, pp. 383-411.

investigations which might show the feasibility of classifying all rocks in a similar manner.

Upon scrutiny of his material and study of analyses of rocks from other localities, Scheerer was persuaded that all highly siliceous igneous rocks could be referred to the three magmas represented by the Saxon gneisses above mentioned, or to mixtures of these magmas. The intermediate and basic rocks he believed could in a similar manner be assigned to six definite chemical types, and in the cited publication Scheerer outlined this chemical classification.

Scheerer's system expresses the idea that the molten material below the solid crust is arranged by specific gravity in zones, each of quite simple stoichiometric composition. He further believed that the upper, more siliceous magmas were first erupted, and the basic ones in late geological periods. From this cause the earliest rocks might be supposed to represent the fundamental magmas more nearly than the basic ones, since the latter magmas must have passed through rocks of varied constitution in reaching the surface, and, therefore, suffered much modification through the fusion and assimilation of fragments torn loose in ascending.

The nine chemical types of Scheerer were arranged in three groups, and named from rocks deemed to represent them in purest form.

| | Oxygen Ratio $SiO_2 : RO+R_2O_3$ ( = 1). | Oxygen Quotient. | Mean silica Percentage. |
|---|---|---|---|
| PLUTONITES: | | | |
| Upper = "Rother Gneiss"...... | 4.50 | 0.222 | 75 |
| Middle = "Mittlerer Gneiss".... | 3.75 | 0.267 | 70 |
| Lower = "Grauer Gneiss"...... | 3.00 | 0.333 | 65 |
| PLUTO-VULCANITES: | | | |
| Upper = Quartz-bearing syenites. | 2.67 | 0.375 | 63 |
| Middle = Syenite.............. | 2.33 | 0.429 | 60 |
| Lower = Melaphyre............ | 2.00 | 0.500 | 55 |
| VULCANITES: | | | |
| Upper = Augite-porphyry...... | 1.50 | 0.667 | 48 |
| Middle = Common basalt....... | 1.33 | 0.750 | 42 |
| Lower = Basic basalt.......... | 1.00 | 1.000 | 36 |

The "Rother Gneiss" corresponded to Bunsen's "normal trachytic" magma, and the augite-porphyry to the "normal pyroxenic" magma.

The primary divisions of Scheerer are obviously very nearly the same as Durocher's acid, hybrid, and basic groups. The types themselves seem to have been established under the control of a genetic theory, and contrary to the evidence afforded by the tables of rock analyses published by Roth three years before the appearance of Scheerer's proposition. The latter does not refer to the conclusions reached by Roth, which were so directly opposed to his own.

*Ferdinand Zirkel, 1866.*—Shortly after the works by Roth, von Cotta, and Scheerer there appeared (1866) a work which may be taken as well representing the stage of development of petrographic system in Germany at the beginning of what may be called the era of the microscope. This work is the *Lehrbuch der Petrographie*, by F. Zirkel, who was to be one of the master spirits of following decades.

This treatise was, and, indeed, still is, a mine of useful information to the student, and its contribution to the systematic science was of much influence. Zirkel's elementary scheme of classification is the following:

A. Original crystalline rocks (" Ursprüngliche krystallinsche").
I. Simple rocks ("Einfache Gesteine").
II. Composite rocks (" Gemengte Gesteine").
    1. Composite crystalline-granular and porphyritic rocks (" Gemengte krystallinisch-körnige und Porphyr-Gesteine").
    2. Composite crystalline-schistose rocks (" Gemengte krystallinisch-schieferige Gesteine").
B. Clastic rocks (" Klastische Gesteine").

This arrangement has elements drawn from various sources. In the grand division into original and clastic (secondary) Zirkel followed Naumann, but returned to von Leonhard for the criterion of the second order. In rejecting von Cotta's system, based on mode of origin, Zirkel remarked that this plan would be highly satisfactory were it not founded upon hypothetical considerations. He secured divisions closely corresponding to von Cotta's eruptive, sedimentary, and metamorphic classes by roundabout means.

In his arrangement of original simple rocks, Zirkel practically followed Naumann.

In the *Lehrbuch* igneous rocks were given the greatest attention. They were brought together in one group by applying three factors at once, as *composite crystalline-granular and porphyritic rocks*. In practice the noncrystalline or vitreous rocks were also included here. This inconsequent proceeding was necessary to bring the eruptive or igneous rocks together, a fact demonstrating that the chosen method of primary subdivision was logically incorrect. The first subdivision of this group was by relative age into the *Older* and *Younger* rocks, a distinction which Zirkel himself recognized was highly artificial.[1] He pointed out that rocks of certain characters had actually received different names, according to age, although the time factor had not been used in their systematic arrangement; and he chose to be logical in application of that factor, to agree with usage, rather than to eliminate the duplicate terms. Had he chosen the latter alternative it is safe to assert that much of the still existing confusion from unnecessary duplicate rock names might have been avoided.

In further systematic subdivision mineral composition and texture were used in ways which have been followed more or less closely by many petrographers to the present time. Following Roth and others it was first determined to consider all rocks of the groups in question as *feldspathic* or *non-feldspathic*. Feldspathic rocks were held to include all in which feldspars or feldspathoids were present in appreciable amount. By this course two very unequal divisions were created and the qualitative element of mineral composition was confirmed in its position of dominance over the quantitative, which has had such unfortunate influence upon systematic petrography to this time.

The plan of forming a great group of feldspathic rocks may have appeared to be desirable on account of the belief, long since

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[1] *Lehrbuch*, Vol. I, pp. 446, 447.

shown to be erroneous, that four kinds of feldspar, namely, orthoclase, oligoclase, labradorite and anorthite, seldom occurred together, and therefore might be used to characterize four great series of rocks. The feldspathoids were used to define another large series.

It appears that in this proposition to use qualitative mineral composition as a leading factor in classification, as in that to apply the age distinction, Zirkel merely gave definite expression to the growing usage of the time, which was practically found in other systems, though not so clearly avowed as a principle. The effect of his proposition to apply geological age and this qualitative element of mineral composition as leading factors in the systematic arrangement of the rocks we now term igneous was peculiarly unfortunate, because this invaluable work of reference was issued at the beginning of the era in which petrographers were to be so busily engaged in the microscopical study of rocks that they had no time for systematic work. In the flood of descriptive literature of the succeeding decade these propositions were adopted almost of necessity. The students from all lands who flocked at this time to Germany to study under Zirkel and other masters, carried the system back to their respective countries, giving it quickly a world-wide usage.

*Ferdinand von Richthofen, 1868.*—Shortly after the appearance of Zirkel's *Lehrbuch* a philosophical discussion of the classification of igneous rocks, as viewed from the geologist's standpoint, was published by the distinguished German traveler and geologist, Ferdinand von Richthofen. This essay was written and published during an extended visit in the United States, under the title "Principles of the Natural System of Volcanic Rocks."[1]

Von Richthofen calls systematic petrography "the most intricate branch of descriptive natural science." He characterizes the earlier systems as artificial, because based upon the idea "that classification should be made dependent on one certain principle previously assumed as the point of issue." The prin-

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[1] *Memoirs presented to the California Academy of Sciences*, Vol. I, pp. 39–133, 1868.

ciples especially named as used in this way are, crystalline texture, lack of stratification, predominance of silicates, etc. To von Richthofen it appeared that the exact mineral composition of rocks as a basis for their classification had become possible after the investigations of Gustav Rose on the feldspars, and that by this means petrography had been brought out of a chaotic state. While acknowledging, therefore, the high value of mineral composition as a basis for classification of igneous rocks, von Richthofen considered that its exclusive application had grouped rocks geologically far separated, and distinguished rocks geologically closely connected, which seemed to him a fundamental error.

The "natural system" of igneous rocks proposed by this author was based upon the Bunsen law of two fundamental magmas, and upon what he considered to be demonstrated facts of a broad correlation between developed texture and age of igneous masses, and of an order of succession of magmas in the history of the earth. By using "eruptive" as a collective term for all rocks under discussion, he implied the adoption of geological mode of origin as the first principle in classification. Von Richthofen remarked that Bunsen's law might have to be revised, "but no change of its principles may ever be expected, as an overwhelming amount of evidence has accumulated in support of its essential tenor." Texture is used by von Richthofen as the second principle in system to produce three classes of eruptive rocks: granite, porphyritic, and volcanic. He says that the conclusion appears to him to be justified "that the three great classes of eruptive rocks are geologically separated and represent three successive and distinct phases of the manifestation of subterranean agencies." The granites of the Sierra Nevada, with which he had personally become familiar, forced von Richthofen to admit that in some parts of the world the ancient granitic and porphyritic eras were succeeded by later eras of the same rocks, within the Mesozoic, but he believed that the volcanic era began with the Tertiary, both in Europe and America. The old lavas of the British Isles, known since the early decades of the century, were either disregarded or overlooked by him.

Mineral composition was regarded by von Richthofen as "essentially dependent on the chemical composition," and was used by him as "more articulate" than the latter, in the construction of his scheme. The outline of von Richthofen's systematic arrangement is as follows:

Eruptive Rocks:
  Class I. Granitic Rocks.
    Orders: 1, Granite; 2, Syenite; 3, Diorite; 4, Diabase.
  Class II. Porphyritic Rocks.
    Orders: 1, Felsitic Porphyry; 2, Porphyrite; 3, Melaphyr; 4, Augitic Porphyry.
  Class III. Volcanic Rocks.
    Orders: 1, Rhyolite; 2, Trachyte; 3, Propylite; 4, Andesite; 5, Basalt.

The further mineralogical variation of rocks was expressed in families under each order.

In this system three principles were applied: (1) Mode of origin; (2) A supposed fact of correlation between age and texture; (3) Chemical composition as represented in mineral composition, and practically expressing the author's belief in the Bunsen law.

While von Richthofen's system was not followed in its details by petrographers, some space has been given to it here because of its influence upon many geologists, perhaps especially in the United States, and because it illustrates so clearly the perils of introducing genetic ideas into the systematic classification of igneous rocks, even when those ideas are believed to be established as laws.

It may be mentioned here that von Richthofen enunciated practically the same views in his *Führer für Forschungsreisende*, issued in 1886.

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*Cordier's system and its influence.*—Turning now to France, before taking up the essays at classification made during the era of the microscope, it appears at first thought strange that for thirty years after Brongniart's classic work no important advance was made in the systematic classification of rocks in that country. And when a very significant advance was made, it appears not to have been recognized. The master spirit of French petrography during this period and until his death was P. L. A. Cordier. He was engaged until the end in carefully elaborating his system of classification, which was presented in lectures and applied to the great collection of the Museum of Natural History in Paris. Cordier does not seem to have published his classification himself, but it was made known by his associate, Charles d'Orbigny, in the *Dictionnaire universel d'histoire naturelle*, article "Roches," and others, Paris, 1842–1848; and in the volume *Description des roches*, etc., edited from the manuscript and lectures of Cordier, published in Paris, 1868, seven years after his death.[1]

The stagnation in systematic petrography in France during this period may be referred to two causes: First, the inherent weakness of Cordier's system; and, second, the traditional custom prevailing in France which gives to the recognized master in any branch of science a strongly dominant influence, which few are willing to openly oppose.

The weakness of Cordier's system came chiefly from the fact that it was, like that of Haüy, based too largely upon the convenient arrangement of cabinet specimens. Viewing rocks simply as aggregates of minerals, they were studied in detail, and their broad relationships were ignored, as belonging wholly to geology. In 1848, only two years before Naumann issued his philosophical analysis of petrography, and 33 years after Cordier published his own first scheme for the arrangement of volcanic rocks, his comprehensive system was announced by D'Orbigny, in the cited article of the *Dictionnaire universel*, etc., to have the following features:

Its fundamental idea was that the classification of rocks should be grouping of *species*, not a subdivision of the grand category of rocks. The species, based upon composition, was

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[1] At an earlier date it was translated into German by Kleinschrod, in *Jahrbuch für Mineralogie*, 1831, p. 17.

regarded as a nearly constant mixture of certain elements and as characterized by a certain structure. Species were supposed to be much more numerous than the unimportant transition types—"roches du passage."

The rock species was determined almost solely on mineralogical grounds. Geological origin and occurrence were used merely as appropriate elements in the description of the species —stating its *habitat*, so to speak.

Species were grouped in genera according to the state of aggregation, as explained below. Orders were based upon the power of the eye to distinguish the character of the rock. The most important of the still larger groups, the family, was formed in most cases upon the *predominant mineral present*, and the families were grouped upon an indefinite chemical basis, in four classes, namely:

Class 1. Earthy rocks (roches terreuses).

Class 2. Saline or acid non-metalliferous rocks (Roches salines ou acidifères non métalliques).

Class 3. Metalliferous rocks (Roches métallifères).

Class 4. Combustible non-metallic rocks (Roches combustibles non métalliques.

Predominance of one mineral constituent, the quantitative factor applied to form families, the most important of divisions aside from the species, was assumed to mean: (1) more than half where two constituents were concerned; (2) more than one-third where three constituents were present, and so on. In complex rocks it was naturally difficult of application and was almost impossible in aphanitic rocks. Moreover, it was not adhered to strictly, as pointed out by D'Orbigny in regard to basalt, which was referred to the pyroxenic family although feldspar might really predominate over pyroxene. As D'Orbigny naïvely remarks: "But it is this latter substance which gives its character to the rock" (Mais c'est cette dernière substance qui donne son caractère à la roche).

The elaborate system of Cordier may be illustrated by the following section, giving the subdivisions within the feldspathic family:

Class I. Earthy rocks (Roches terreuses).
  First family, feldspathic rocks (Roches feldspathiques).
  1. Order. Phaneromeric—of which the constituents are visible to the naked eye (Phanérogènes dont les éléments sont visible a l'œil nu).
    1. Genus. Aggregates (agrégées).
      Species: (1) harmophanite, (2) leptynite, (3) gneiss, (4) pegmatite, (5) granite, (6) syenite.
    2. Genus. Conglomerates (Conglomérées).
      Species: (1) feldspathic breccia, (2) feldspathic conglomerate, (3) feldspathic grit and sandstone.
    3. Genus. Unconsolidated sands, etc. (Meubles).
      Species: (1) Feldspathic sands and gravels (sables et graviers feldspathiques), (2) pebbles and débris of feldspathic rocks (galets et débris de roches feldspathiques).
  2. Order. Aphanitic—wholly or partially (Adélogènes en tout ou en partie—dont le volume des parties est en totalité ou en partie invisible).

Other families of earthy rocks are named after pyroxene, amphibole, garnet, hypersthene, diallage, talc, mica, and quartz. An inconsequent element in the construction of the system, found in various places, is illustrated in the eleventh family, vitreous rocks, introducing a new factor while stating that the rocks in question are *feldspathic*.

The great majority of known igneous rocks are assigned by this system to the aphanitic (adélogène) orders of the various families, because their constitution is not wholly determinable by the naked eye.

The system of Cordier was the system of France for years after his death, in 1861, and was published in elaborate form by D'Orbigny in 1868.[1] In all essential particulars the system had remained unchanged. At the beginning of the chapter upon the principles of classification is the declaration: "The description of rocks requires in advance: (1) the formation of species; (2) their classification" (La description des roches exige avant tout: 1° l'institution des espèces; 2° leur classification). There is so

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[1] CHARLES D'ORBIGNY, *Description des Roches, etc.* Rédigé d'après la classification, les manuscrits inédits, et leçons publiques de P. L. A. Cordier. Paris, 1868.

little new in the construction of the system that no further analysis of it seems necessary.

No influence of Cordier's principles can be detected in modern systems for the classification of rocks. The importance of his system from the standpoint of this review lies in the retarding influence it exerted for several decades over the development of the science in the country where Brongniart had laid such logical foundations. But it seems to the writer that it was after all not so much the inherent weakness of Cordier's system as it was his domination over the thought of his countrymen, to a degree possible only in France, that retarded progress for so long. It is significant to recall that D'Orbigny's last presentation of the system appeared two years later than the *Lehrbuch* of Zirkel, but far more so to note, in confirmation of the opinion just expressed, that it was published eleven years after an important treatise on rocks, issued in Paris by a French geologist of renown, presenting a broad and logical view of petrographic system, which was not even referred to by D'Orbigny.

*H. Coquand, 1858.*—In 1858 there was published in Paris a work by H. Coquand, the title of which, translated, is as follows: *A Treatise on Rocks, Considered from the Point of View of Their Origin, Their Composition, Their Occurrence, and Their Use in Geology and Industry.* This book has over four hundred pages, and contains a classification of rocks very different from any earlier or contemporary scheme, but it has received very little recognition in spite of its merits. Coquand was professor of mineralogy and geology in the College of Besançon. Possibly he did not belong to the distinguished coterie of Parisian geologists, and in that case the fact that he should come out with a system full of originality, strongly opposing that of Cordier, who was still alive, may have been regarded by his contemporaries as such a flagrant violation of unwritten law that the only course open to them was to ignore his proposed scheme of classification.

The title of Coquand's treatise shows at once how completely he had broken away from the traditions of his countrymen. His classification has little in common with other French systems, and, if not wholly original, one must suspect the dominant influence of Naumann's views. Its main outlines are as follows:

Three families of rocks are recognized:
  I. Igneous rocks.
  II. Aqueous rocks.
  III. Metamorphic rocks.

Igneous rocks are divided into three groups:
  1. Granitic (in the sense of granular).
  2. Porphyritic.
  3. Volcanic.

Aqueous rocks into three groups:
  1. Chemical deposits.
  2. Mechanical deposits.
  3. Carbonaceous rocks, of vegetable origin.

Metamorphic rocks into three groups:
  1. Crystalline schists.
  2. Those of chemical origin.
  3. Those of mechanical origin.

It will be seen that this system is in its outline wonderfully like many of recent years in its logical use of factors in construction, and in the order of their application. In further subdivision, finally producing species, Coquand was less fortunate, being governed still by the mineralogical idea too closely. Probably he was much less fitted for the descriptive task than Cordier, who doubtless surpassed him in intimate knowledge of the detailed characters of rocks as cabinet specimens; but he certainly possessed a logical mind, and grasped far better than his contemporaries the relations of petrography to geology.

*Archibald Geikie, 1872.*—Turning to the literature of other countries during this period, it is evident that systematic petrography was developed as a science almost wholly through the labors of workers in Germany and France. Prior to the microscopical era, soon to be considered, practically no special students of this subject appeared in either Great Britain, America, or in other countries. Aside from the discussions of geologists, like De la Beche, already mentioned, there was in Great Britain no important contribution after the time of Macculloch. The conditions in that country up to 1870 may be summarized by the statements of Archibald Geikie, in 1872, in the *Students' Manual of Geology.* He there says: "There is as yet no good English treatise on petrography, or the classification and description of rocks." In this work all rocks are first classified "under the four great heads of igneous, aqueous, aerial, and metamorphic, according to the nature of the agencies by which they have been brought into their present state and position." "Igneous rocks without exception are composed of minerals which are silicates. These minerals may be said to belong to two great classes: silicates of magnesia and silicates of alumina," each combined with other bases. "The felspars are the bases of all truly igneous rocks, those in which no felspar or mineral of that type is present being very few and unimportant, even if they exist at all." Here we see the proposition made by Zirkel stated in extravagantly positive terms.

Igneous rocks are divided into volcanic, trappean, and granitic, with crystalline and fragmental subdivisions under the first two. The trappean class is vague and "of convenience only." In the volcanic class the law of Bunsen is practically recognized and two groups established: "the trachytes, or felspathic or acidic group," and "the dolerites, or pyroxenic or basic group." Similar groups are formed under the trappean class. The granitic class embraces only granite and syenite.

## PART II.

*Beginning of the microscopical era.*—Having presented the state of systematic petrography up to the time when the polarizing microscope became the instrument of prime importance in the investigation of rocks, we now proceed to the study of the more recent schemes of classification, based upon the larger knowledge. For all systems thus far reviewed, it must be recognized that ignorance of the characters and relationships of many rocks rendered a comprehensive and logical scheme impossible. The frame work of system was necessarily constructed without full knowledge of the applicability of some of the factors employed. With the polarizing microscope and improved methods of chemical analysis this condition has now disappeared, and while the time may not be ripe for unbiased criticism it is plain that modern systems of classification must ultimately be judged with regard to the greater and almost perfect knowledge of the actual characters of rocks enjoyed by the authors of those systems. The responsibility for the choice of factors suitable for the construction of a comprehensive system and for a logical, consequent, and consistent application of those factors clearly increases with knowledge of the objects to be classified.

The microscopical study of rocks, continuing for nearly four decades with ever improving facilities and methods, has added a vast store of knowledge concerning the characters of these objects. Revelations concerning the composition of types long known have often been astonishing. The essence of rock structures has been made clear. The uttermost parts of the earth have been searched, and many new and interesting varieties have been discovered—not all in distant fields, but often close at hand. For new structures and new types, new terms have been proposed, and the nomenclature has thus expanded enormously. In the light of new discoveries, old conceptions have given way to new ideas, and the terms expressing them have yielded to new ones, or, in too many cases, the old nomenclature has been retained with new definitions. But while the last third of the nineteenth century may be termed the microscopical period of petrography, great additions to our knowledge of rocks were also made in this period on all older lines of study, and especially by quantitative chemical analysis and by investigations as to the modes of occurrence and the field relations of different rocks.

This review, which deals with system, must trace the application of new or revised principles to classification during this period of rapid addition to knowledge. It is perhaps quite natural that the greater part of the systematic advance was in partially worked out revisions of old schemes—grafting some new idea to the old trunk. It is also natural that the greatest work has been in the field to which the microscope has been particularly applied, so that at times petrography has been treated as though narrowed to the microscopical petrography of igneous rocks.

While the flood of microscopical rock studies was at its height, it was manifestly impossible for anyone to do more than to present the new information in comprehensive form, without finished attempt to apply it to the systematic arrangement of rocks. It is with this condition in mind that the important works upon microscopical petrography, issued in the decade 1870 to 1880, must be judged. Their actual effect upon the systematic science was, however, very great, from the mere fact that they exerted a controlling influence over the usage of a multitude of workers.

*Ferdinand Zirkel, 1873.*—In 1873 appeared *Die mikroskopische Beschaffenheit der Mineralien und Gesteine*, by F. Zirkel. The systematic point of view occupied by this authority at this time is expressed in the following tabular analysis of his larger divisions of rocks:

A. Non-clastic rocks ("Nicht-klastische Gesteine").
  I. Simple ("Einfach").
  II. Composite ("Gemengt").
    1. Massive ("Massig").
      *a.* Feldspathic ("Feldspath-haltig").
      *b.* Non-feldspathic ("Feldspath-frei").
    2. Schistose ("Schieferig").
B. Clastic-secondary rocks ("Klastische-deuterogene-Gesteine").

Comparing this scheme with that of the *Lehrbuch der Petrographie*, we find that the microscope has convinced Zirkel that *crystalline* cannot be appropriately opposed to *clastic*. He also believes that *original* cannot be used for non-clastic rocks because they have been discovered to be at the present time in part composed of alteration products. He therefore falls back on a negative term, *nonclastic*, admitting that it is indefinite—"misslich." *Massive* is defined as *not schistose, in larger part granular*—"nicht geschiefert, zum grossen Theil körnig."

The work deals mainly with the *feldspathic, massive, composite, non-clastic rocks*. These are subdivided as follows:

I. Orthoclase rocks.
  1. With quartz.
  2. Without quartz, with or without plagioclase.
  3. Without quartz, with nephelite (or leucite).
II. Plagioclase rocks.
  1. With hornblende.
  2. With augite.
  3. With diallage.
  4. With hypersthene.
  5. With mica.
  6. With olivine.
III. Nephelite rocks.
IV. Leucite rocks.

The use of the soda-lime feldspars—oligoclase, labradorite, and anorthite, as factors in the subdivision of feldspathic rocks, found in the *Lehrbuch*, had been shown by the microscope to be an error, and it disappears without comment. The mineral composition of rocks is here applied to their classification in a qualitative way almost exclusively. Zirkel remarks: "To the non-feldspathic, non-schistose, composite rocks belong among others: eclogite, tourmaline rock, olivine rock, eulysite and saussurite-gabbro." Of these only three are described and within a compass of two pages.

The age distinction in classification of igneous rocks is freely characterized by Zirkel as unnatural and undesirable and it is not formally recognized in this work as it was in the *Lehrbuch*, yet he could not see his way to carry out the reform necessary to its rejection and retained in description many of the duplicate terms based on it.

*Structure* and *crystalline condition* were not given a defined rôle in Zirkel's new system, but in practice the granular, porphyritic, fluidal and glassy forms were distinguished.

*A. von Lasaulx, 1875.*—The *Elemente der Petrographie*,[1] by A. von Lasaulx, issued in 1875, is another attempt to utilize the results of microscopical study of rocks in their classification and description. Von Lasaulx believed that since there are no true rock species, and since transitions in all directions are most common, classification must consist in the establishment of *types*, about which should be grouped the intermediate kinds of rocks. He announced as his guiding principle that rocks must be classified upon the basis of simple, definitely known and easily recognized, morphological properties. Genetic criteria did not seem to him applicable because always more or less hypothetical and in some cases entirely so. He, therefore, discards the primary classification of rocks on genetic principles, advocated by von Cotta and others, and returns to von Leonhard's elementary division into *Simple*, *Composite* and *Clastic* rocks, omitting the *Apparently simple* class as no longer necessary.

The morphological characteristic of rocks chosen by von Lasaulx as most applicable to the systematic subdivision of the classes mentioned was the degree or distinctness of crystallinity, which is surely the most variable of all their properties, and hence least adapted to the formation of well-defined groups. The major divisions formed by von Lasaulx are as follows:

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[1] *Elemente der Petrographie*, Bonn, 1875, pp. 486.

*Simple Rocks:*

- A. Non-crystalline (amorphous) or semi-crystalline.
- B. Crystalline granular.
  - *a.* Really simple.
  - *b.* Rocks forming transitions to Composite group through the appearance of vicarious constituents (*e.g.*, amphibolite, serpentine, etc.).

*Composite Rocks:*

- A. Massive.
  - *a.* Amorphous, glassy (obsidian, etc.).
  - *b.* Semi-crystalline (including vitrophyres).
  - *c.* Crystalline.
    - 1. With abundant glassy base (basalt, etc.).
    - 2. With microaphanitic more or less individualized groundmass.
      - *aa.* Groundmass alone (felsite, etc.).
      - *bb.* True porphyries (felsite-porphyry, etc.).
    - 3. Rocks which are almost completely crystalline, mainly pseudo-porphyritic, etc. (phonolite, hornblende-andesite, etc.).
    - 4. Crystalline granular.
      - *aa.* Feldspathic (granite, etc.).
      - *bb.* Non-feldspathic (Greisen, eclogite, etc.).
- B. Stratified Rocks:
  - *a.* Feldspathic (gneiss, etc.).
  - *b.* Non-feldspathic (mica-schist, etc.).

*Clastic Rocks:*

- A. Semi-clastic (clay slate, kaolin, tuff, etc.).
- B. Purely clastic.

Mineral composition is applied as a factor to produce the commonly recognized rock types within these groups. It will be noted that many of the divisions above mentioned are not only quite indefinite but they are, also, inconsequent. Thus three out of four divisions of *crystalline massive* rocks are but *partly* crystalline.

Meteorites are described by von Lasaulx in an appendix. Concerning this treatment he remarks that it is the first time that cosmic rocks have been given a place in a text-book of petrography, but that it seems useful, for purposes of comparison, to have them described in the same work with the terrestrial rocks.

*H. Rosenbusch, 1877.*—Another important summary of the results of the microscopical investigation of rocks appeared in 1877, under the title *Mikroskopische Physiographie der massigen Gesteine*, by H. Rosenbusch. There was in this work but slight discussion of principles of classification, and the only new factor of note in the system used is the idea expressed in the title, which requires some explanation. All rocks were divided into two classes:

I. Massive rocks (" Massige Gesteine ").
II. Stratified rocks (" Geschichtete Gesteine ").

A class of Metamorphic rocks was not considered feasible.

" Massive " and " stratified," as used by Rosenbusch in this connection, do not refer to rock textures, as one might suppose from the historic use of the terms; for this primary division was avowedly intended to express an idea, first brought out by Lossen (which will be referred to more fully in a later section of this review), that the most important relation of rocks is the formal one to the earth sphere. Rocks may be considered as having been formed, either at the surface under the influence of gravity, in more or less concentric shells or strata, or, in eruptive bodies of irregular shape and position not determined by gravity. Under this conception all rocks are either stratified or massive. Massive rocks in this sense are also eruptive rocks, but Rosenbusch chose to use the former term in systematic petrography because free from the genetic conception involved in the latter. In view of the evolution of this master's ideas, presented in later works, his language will be quoted:[1] " The former name is to be preferred because it refers only to an undeniable form of occurrence, and involves no possible prejudice concerning genetic relations."

The controlling criteria in the further construction of Rosenbusch's scheme will be apparent from the following partial tabular statement:

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[1] " Der erste Name ist vorzuziehen, weil er sich lediglich auf eine unläugbare Erscheinungsform bezieht und keinerlei irgendwie geartetes Präjudiz über die genetischen Verhältnisse involvirt."

Massive rocks.
- A. Orthoclase rocks.
  - *a*. Older.
    - I. Quartzose.
      - 1. Granular = Granite Family.
      - 2. Porphyritic = Quartz porphyry Family.
      - 3. Vitreous = Felsite-Pitchstone Family.
    - II. Quartz free (3 families similar to those above).
  - *b*. Younger.
    - I. Quartzose.
      - 1, 2. Granular or porphyritic = Liparite Family.
      - 3. Vitreous = Family of the acid glasses.
    - II. Quartz free (with families as above).

The other large groups are the following :

- B. Orthoclase-Nephelite, or Orthoclase-Leucite rocks.
- C. Plagioclase rocks.
- D. Plagioclase-Nephelite, or Plagioclase-Leucite rocks.
- E. Nephelite rocks.
- F. Leucite rocks.
- G. Non-Feldspathic rocks. Of the Non-feldspathic rocks Rosenbusch remarked[1] that they were all rich in olivine, and might therefore be called *Olivine rocks*.

Each of these groups has Older and Younger divisions, and, within these, families, established in a manner similar to that given for the orthoclase rocks.

In this arrangement *mineral composition* is used, as in Zirkel's system. The *age distinction* is applied without discussion. *Texture* is given a prominent rôle, and *chemical composition is not used.*

*Fouqué and Michel-Lévy, 1879.*—The first effects of the microscopical study of rocks upon petrographic system in France may be seen in the *Minéralogie micrographique*, by F. Fouqué and A. Michel-Lévy, which was published in 1879. While presented as an "Introduction à l'étude des roches éruptives françaises," there is in this work some discussion of principles of classification, and a tabular view of the scheme in use by the

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[1] "Sie siend sämmtlich reich an Olivin, daher kann man sie kurz als Olivignsteine bezeichnen."

authors. Although the system in question has not had much influence except in France, it is of interest from certain new and peculiar conceptions which are given classificatory value in it.

It is first to be noted that Fouqué and Michel-Lévy abandon almost entirely the system of Cordier. Although affirming that rocks are simply the most abundant natural associations of minerals ("les roches ne sont autre chose que les associations minérales naturelles le plus fréquentes"), they proceed to their arrangement under the stated principle that a rational classification of rocks in general must be based upon the following three fundamental characters, namely: (1) The mode of formation; (2) the geological age; (3) the specific mineral properties. The last named character comprises: (*a*) the nature of the integrant minerals; (*b*) the structure of the rock.[1] By the application of the first factor they separate eruptive rocks from those deposited as sediments or as vein filling. By the factor of geological age (the applicability of which is not discussed) they distinguish clearly—"nettement"—between pre-Tertiary and Tertiary or post-Tertiary rocks. It is believed that the same types occur in both groups, following approximately the same order of eruption, with predominance of basic rocks and a tendency to the vitreous condition in the most recent occurrences. In these respects the new French system is practically like others which have been reviewed, but in the use of ***structure*** and ***mineral composition*** for the main framework of their system. Messrs. Fouqué and Michel-Lévy apply certain peculiar conceptions requiring some analysis.

Considering that in practically all eruptive rocks there have been two (or more) distinct periods of formation of the primary mineral grains, these authors proceed to give a strangely artificial weight to the products of the second period, both in

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[1] "Un classement rationel des roches, en général, doit s'àppuyer sur les trois caractères fondamentaux suivants: 1° le mode de formation; 2° l'âge géologique; 3° la spécification minéralogique. Ce dernier caractère comprend: (*a*) la nature des minéraux intégrants; (*b*) leur structure d'association (structure de la roche.)"

definitions of structure and in classifying rocks by mineral composition. The structures of eruptive rock applied in classification are brought under two groups: "structures granitoïdes" and "structures trachytoïdes." The essential difference between the two is conceived to be that in the granitoid the grains of the two periods of consolidation resemble each other, because of similar conditions of consolidation in the two periods, while in the trachytoid structure there is a marked difference between the two products as a result of changed conditions in the later period. In the rocks commonly called granular it is thought that two generations of mineral grains of approximately the same formal character may usually be recognized. Where no distinction can be made it is rather paradoxically assumed that the grains all belong to the *second* period. But it is to be noted that without this assumption the scheme of Fouqué and Michel-Lévy, as it stands, could not classify such a rock. Porphyries in which the groundmass is granular are, from that fact, classed with perfectly granular rocks.

Under the granitoid group of structures three varieties are recognized: (1) Granitoid proper, in which each individual grain has approximately equal dimensions in all directions, variation in size being disregarded; (2) pegmatoid, the regular or graphic intergrowth of two minerals of simultaneous crystallization; (3) ophitic, characterized by elongated feldspar crystals, and forming a transition to the microlitic structure.

The trachytoid group of structures has likewise three varieties: (1) *Type pétrosiliceux*, characterized by bands of minute spherulites and the presence of the mysterious substance petrosilex or microfelsite; (2) *type microlithique*, characterized by microlites of feldspar, and of other minerals; (3) *type vitreux*, characterized by predominance of amorphous substance.

In explaining the microlitic type the authors point out that their synthetic experiments prove that such microlites are products of *pure igneous fusion*, indicating to them a fundamental difference between the trachytoid and the granitoid structures, since they believe that certain mineralizing agents ("agens minéralisateurs") are necessary to the latter development.

This view of rock structures makes the shape of the mineral grains all important and casts aside the formal relationship prominent in the porphyritic structure as of little value. The equidimensional *grain* and the elongated *microlite* are placed in fundamental opposition to each other.

The mineralogical composition of rocks is applied for their classification in a qualitative way, similar in some respects to that adopted by the German petrographers, but with the all important modification that *only the minerals of the second period of consolidation are considered.* Such a principle may be designated as subjective, extremely unnatural and highly artificial. There is in this system no attempt to express the chemical composition of the rock in terms of its minerals, for in some cases all the minerals of a rock are used in its classification, where there was no *first* period of consolidation, and in other cases only a small portion of the constituents, as in porphyries with abundant phenocrysts and microlitic groundmasses. Since in porphyries this portion of second consolidation bears no definite quantitative relation to the mass as a whole it must often happen by this system that rocks of widely different chemical composition will be brought together and, conversely, that rocks of the same chemical character and even of the same magma will at times be separated. For example, certain intrusive quartzose hornblendic diorite-porphyries of the Rocky Mountain region, in which hornblende and plagioclase are developed entirely in phenocrysts, would fall among the microgranulites while their granular equivalents would be quartz-diorites. It is also clear that all but granular rocks would be classified in this scheme by their most obsure constituents, often to the neglect of every prominent megascopic character, and systematic petrography would become purely a microscopical science. It is interesting to recall at this point the principle announced by these authors and quoted above that a rational classification of rocks must be based upon the " fundamental characters " whose application has been reviewed.

In practice, Fouqué and Michel-Lévy give the first importance to the colorless constituents, quartz, feldspars, feldspathoids, etc., to produce series within which the ferromagnesian minerals are used to make subdivisions. The existence of certain phenocrysts is recognized, in the naming of rocks, in a few cases only.

The petrographic system for eruptive rocks elaborated by Fouqué and Michel-Lévy in 1879 has remained the system of France to the present time, with but slight change.

In 1889 Michel-Lévy compared the results of their system with those of the Rosenbusch system, soon to be discussed, in a work entitled *Structures et classification des roches éruptives*.[1] This discussion presented no new propositions of note excepting a plan of expressing the structure and mineral composition of any given rock by a formula. The principles which must govern the classification of eruptive rocks are concisely stated as follows:

> It is neccessary to base the classification and nomenclature of rocks upon positive facts, independent of all hypothesis. Modern petrography possesses the means to accomplish this end, since the principal structures or modes of association of the minerals are well known and the minerals themselves may be determined with precision. It is, then, exclusively structure and mineral composition which must be relied upon in the classification and nomenclature of rocks.[2]

It is to be remarked, once more, that chemical composition is not taken into account by Michel-Lévy, either directly or indirectly, since the partial mineral composition used by him in classification is clearly not an expression of the chemical composition of the magma nor of any definite part of it. The substance classified is not the rock but merely that variable portion of the rock which the investigator judges was in a fluid or pasty

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[1] Paris, 1889, pp. 93.

[2] "Notre conclusion, . . . . est qu'il faut baser la classification et la nomenclature des roches sur des faits indépendants de toute hypothèse, et de nature positive. La pétrographie moderne dispose de moyens suffisants pour atteindre ce but sans hésitation: on est d'accord sur les principales structures d'association des minéraux des roches; on sait déterminer ces minéraux avec précision. C'est donc *exclusivement* sur la structure d'association et sur la composition minéralogique que nous persisterons à nous appuyer pour classer et nommer une roche." *Loc. cit.*, p. 87.

condition at the beginning of the second period of consolidation —the "pâte."

*Samuel Allport.*—During this period in which Zirkel, Rosenbusch, Fouqué and Michel-Lévy were formulating more or less distinct advances in systematic petrography, the English students of rocks made but slight positive contributions in this direction. The condition of the science may be best appreciated by reference to the various short discussions of principles of classification by Samuel Allport. This careful investigator often pointed out the fallacy of the age distinction, so clearly illustrated by the long-known ancient lavas of the British Isles, and also the importance of Judd's discovery of the intimate relationship of coarsely crystalline and volcanic rocks. This was cited to disprove the idea that a sharp line could be drawn between the Plutonic and Volcanic rocks. But Allport considered it premature to suggest any great changes either in classification or nomenclature.

*Clarence King, 1878.*—In America no original contributions to systematic petrography were made prior to the microscopical period. The earliest use of the knowledge gained in that period was probably by Clarence King,[1] whose appreciation of its value led to the report upon the Microscopical Petrography of the 40th Parallel rocks by Zirkel, and who, also, applied certain supposed facts resulting from microscopical research in his own discussion of the classification of volcanic rocks. The proposition referred to has had little influence upon petrographic system, but has a certain importance from the standpoint of this review as illustrating again the dangers of applying genetic ideas in the classification of igneous rocks.

King accepted the law of Bunsen and the law of succession of volcanic rocks advocated by von Richthofen, which have been stated. He also considered that "a sharp line is to be drawn between the so-called Plutonic rocks and the true igneous ones." The microscopical studies of which he had knowledge led him to the strongly stated conclusion that "all the volcanic rocks

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[1] Report of the Geological Exploration of the Fortieth Parallel, I. *Systematic Geology*, pp. 705–25, Washington, 1878.

show abundant evidence of fusion in the presence of glass base and glass inclusions, while the group which is typified by granite never shows the slightest trace of the effects of fusion." All known characters of plutonic rocks are interpreted as proving them to be extreme products of the metamorphism of sediments. After discussion of the cause of generic differences of volcanic rocks, in which certain new hypotheses concerning magmatic differentiation are developed, King proposes the following systematic arrangement for the family of volcanic rocks, including therein all believed to be of truly igneous origin:

*Genera.*—(1) Propylite; (2) Andesite; (3) Trachyte; (4) Neolite. Expressions of time, according to von Richthofen's law of succession, and of depth owing to secular refrigeration.

*Species.*—Expressions of chemical differentiation by specific gravity of mineral ingredients, grouping under the law of Bunsen.

Three species only were recognized under each genus, representing respectively the quartz, biotite or hornblende, and pyroxene-bearing forms.

*Varieties.*—Expressions of range of texture according to predominance of secreted crystals, groundmass, or base.

*M. E. Wadsworth, 1884.*—Under the title *Lithological Studies; A Description and Classification of the Rocks of the Cordilleras*, M. E. Wadsworth published, in 1884, the first part of a projected comprehensive work, intended to present a new classification of rocks. This first part was devoted to a discussion of principles and the beginning of the descriptive portion. Wadsworth denounced all existing systems as highly artificial, and stated, as the basis of his own more natural system, the belief that "the older rocks now classed as distinct species are rocks that were once identical with their younger prototypes." "The order [of his system] will be to pass from the glassy to the most perfectly crystalline state; from the least altered to the most altered; from the most basic toward the most acidic; from the non-fragmental to the fragmental or clastic." He plunged at once into a description of ultrabasic rocks, without explaining the proposed application of his asserted principle to the construction of a system, and no further portions of the projected work have appeared. It is plain that the basis of Wadsworth's conception is contrary to known facts of petrogenesis. A direct contribution to petrographic system is afforded by the proposition made by Wadsworth to group terrestrial and meteoric masses together, applying to them a single system and nomenclature. The descriptive portion of the published work is, in fact, mainly occupied with discussion of meteorites rich in iron. Wadsworth thus goes a step further than von Lasaulx, who treated meteorites in an appendix to his discussion of terrestrial rocks.

It is hoped that the trend of the evolution of systematic petrography during the earlier portion of the microscopical era has been fairly indicated in the preceding pages. The tendency, most natural under the circumstances, was to overestimate the systematic importance of some of the discoveries made through the microscope, and to slight other, more fundamental, properties or relations of rocks. Many new rock names were proposed and usage became fixed and extended in directions where it had never been well grounded. Protests against the tendency of the times were numerous, and especially from the geologist's standpoint. Many of these protests were of little influence, because based upon imperfect appreciation of the situation; others were far too conservative in spirit.

*J. D. Dana, 1878.*—As an example of the conservative geologist's view at this time may be cited the discussion of petrographic system by J. D. Dana in an article published in the *American Journal of Science* in 1878 under the title "On some Points in Lithology."[1] This article refers to the *Mikroskopische Physiographie* of Rosenbusch, and to other recent works, and may be taken as expressing the author's view of petrography at the stage of its development just reviewed.

Lithology, according to Dana, is charged with the descrip-

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[1] *Amer. Jour. Sci.*, 3d ser., Vol. XVI, p. 335. 1878.

tion and naming of rocks. It has "to note down their distinctions in such a manner as shall best contribute to the objects of geology." "From granite down they [rocks] are with very few exceptions mixtures of minerals, as much so as the mud of a mud bank." "Strongly drawn lines exist nowhere." "Rocks are therefore of different *kinds*, not of *different species;* and only those mixtures are to be regarded as *distinct kinds* of rocks which have a sufficiently wide distribution to make a distinct name important to the geologist."

Dana discusses the bases of classification adopted by petrographers of this time, such as age, structure, and contents in certain minerals, and objects to most of them as trivial or wrongly used. He then proposes an arrangement of the "Crystalline rocks, exclusive of the calcareous and quartzose kinds," under the following groups :

I. Mica and potash feldspar series — Granite, gneiss, mica schist, trachyte, etc.

II. Mica and soda-lime feldspar series — Kersantite, kinzigite, ditroite, phonolite, etc.

III. Hornblende and potash feldspar series — Syenite, hornblende-schist, foyaite, etc.

IV. Hornblende and soda-lime feldspar series — Diorite, andesite, euphotide, etc.

V. Pyroxene and potash feldspar series — Amphigenite.

VI. Pyroxene and soda-lime feldspar series — Augite-andesite, norite, dolerite, etc.

VII. Pyroxene, garnet, epidote, or chrysolite rocks, containing little or no feldspar, lherzolite, dunite, garnetite, etc.

VIII. Hydromagnesian and aluminous rocks. Chloritic, talcose, and other schists, serpentine, etc.

While Dana does not refer in this article to the broader grouping of rocks, it appears, from various editions of his *Manual of Geology*, that he uses mode of origin to distinguish the three great classes — Igneous, Sedimentary, and Metamorphic — in discussing that question; but, in arranging rocks for description, he abandons that principle, and makes another division as more convenient. Convenience of presentation, and not expression of natural relations, is really the object of Dana's arrangement. It is, therefore, not strictly a petrographic system. In the second edition of the *Manual* (1874), igneous and metamorphic groups were separated in description; but, probably for the reason that such a course involved the splitting up of granitic, syenitic, and other types supposed to be metamorphic in part and eruptive in part, Dana had, in 1878, evidently adopted the arrangement found even in the last edition of the *Manual* (1895), whereby *crystalline* and *fragmental* were opposed to each other, as by Zirkel in 1866.

Dana was never able to adopt the modern petrographic systems, founded so largely upon erroneous assumptions, like the age distinction among igneous rocks, or upon genetic views with which he was not in accord, and contented himself with an arrangement of convenience. The main features of this order of description appearing in the *Manual of Geology*, 1895, are seen from the four primary groups under which all rocks were treated:

1. Limestones, not crystalline.
2. Crystalline limestones.
3. Fragmental rocks, not calcareous.
4. Crystalline rocks.

The crystalline rocks were described under five heads:

I. Siliceous rocks or those consisting mainly of silica.
II. Rocks having alkali-bearing minerals as chief constituents.
III. Saussurite rocks.
IV. Rocks without feldspar.
V. Hydrous magnesian and aluminous rocks.

The second group was divided nearly as in the proposition of 1878, above cited. This resulted in bringing together such unlike things as granite, greisen, minette, slate, agalmatolite, porcelain jasper, obsidian, etc., in the "Potash Feldspar and Mica Series."

*Karl A. Lossen.*—Among other protests raised by geologists against the tendency to treat rocks fom the microscopist's alleged narrow standpoint, one of the more philosophical discussions had an acknowledged effect making it worthy of notice; namely, that by Karl A. Lossen, himself a petrographer of distinction, yet in first degree a geologist, prominent upon the Prussian geological survey.

The views held by Lossen were repeatedly expressed, and were summed up in a discussion of principles entitled *Über die Anforderungen der Geologie an die petrographische Systematik.*[1] The "demands" here forcibly expressed are based upon the idea that, ***because the rock is a geological body, the geological relations of rocks must be recognized as petrographical relations.*** Of all the geological relations of rocks Lossen selected that which seemed to him the most important, and claimed that that principle should be used as the primary factor in petrographic classification. The relation of rock masses to the earth sphere appealed to Lossen as all important, and on that criterion all rocks were considered as ***stratified*** or ***massive.*** Stratified rocks were defined as those accumulated upon the earth's surface under the controlling influence of gravity, causing them to assume in some degree the form of concentric strata normal to the radius of the earth. The material of massive or eruptive rocks, on the other hand, was viewed as having been forced from the depths directly against the influence of gravity, consolidating like a casting, under the control of surrounding conditions. Surface lavas, spreading out in sheets, while controlled largely by gravity in their formal relations, were referred by Lossen to massive rocks, because possessing the resemblance to a casting from one pouring, and not as built up by successive additions, layer upon layer. It will be seen that the molten condition of magmas was actually a leading factor in Lossen's idea, although the avowed intention in using ***eruptive*** as an alternative for ***massive*** was to express the force opposed to gravity, and not the molten state which rendered them susceptible to that force.

Lavas are not the only rock masses difficult of consistent treatment under Lossen's principle. Pyroclastic tuffs were considered as illustrating the fact that "das Ineinandergehen zum Wesen der Gesteinsnatur gehört." Lossen confessed, further, that rocks of the first crust of the earth, according to the nebu-

[1] *Jahrbuch der k. pr. geol.* Landesanstalt, 1883, p. 486.

lar hypothesis, would necessarily be separated from his eruptive class, but he considered this point immaterial because he doubted whether any such rocks were known. Metamorphic rocks are of such diverse origin and present such difficulties to the systematist that Lossen considered it inadvisable to treat them as a distinct class.

In this discussion by Lossen, as in the majority of those emanating from geologists, no appropriate distinction is made between the rock mass as a formal unit and the material within it, the rock proper. The primary division of Lossen is one of rock masses, not of rocks. The consideration of the form and position of these masses with regard to the controlling influence of gravity or the opposing eruptive force, leads to only one of many ways in which the geologist must classify rock bodies. Other elemental subdivisions of the same bodies are necessary. The geologist is, indeed, obliged to make and discuss all such fundamental distinctions. The petrographer, on the other hand, should not only be at liberty to select, but, in order to secure logical excellence for his system, *must* choose, as his primary principle, that one most closely connected with the factors which he has adopted for use in the further construction of the systematic arrangement of rocks. It is clear that all igneous rocks, those produced by the consolidation of molten magmas, possess, from this origin, material properties most useful in their detailed classification. If arrangement by a certain characteristic due to this origin is desired, it matters not where the rocks occur in the earth. They may belong to the primeval crust, or form injected masses of whatever size, shape, or attitude, or appear on the surface in lava streams. If it was mode of origin, not formal relations to the earth, which gave igneous rocks the common characters used in their systematic arrangement, then mode of origin is logically the principle to be used by the petrographer to bring them into one grand division.

*H. Rosenbusch, 1887.*—As has been mentioned, the force of Lossen's claim, as made in earlier publications, was admitted by H. Rosenbusch, in the first edition of his *Mikroskopische Physio-*

*graphie der massigen Gesteine*, "massig" being used in the sense explained by Lossen, and not in that of textural condition. In the second edition of this widely-used handbook, which appeared in 1887, Rosenbusch repeated his approval of Lossen's proposition, and in the revision of his petrographic system further emphasized geological occurrence as a factor of prime classificatory value for eruptive rocks. The great changes in system found in this volume make it practically a new work, but a detailed statement of its scheme seems unnecessary since all petrographers may be assumed to be familiar with it.

In the decade since the appearance of the first edition, Rosenbusch effected a complete change of systematic base in some important respects, the reasons for which are given in the preface. He now considers rocks as the documents in which the history of the earth is written, and petrography, as the science which teaches us how to decipher those documents, becomes to him *a historical and not a descriptive science*. To quote his declaration:

> The recognition of these relations made the new edition of this book practically a new work. Its end will have been achieved if I have succeeded in procuring for this fundamental conception a general acceptance, and have demonstrated that rock structure affords the safest and most productive means for the construction of a natural system of rocks.[1]

A natural system of rocks must therefore be historical, *i. e.*, genetic. Plainly the logical analysis of the broad science of rocks presented by Naumann was either forgotten or ignored by Rosenbusch.

With this statement of controlling principles in mind, one involuntarily recalls that in the first edition of the *Mikroskopische Physiographie* the rocks to be discussed were designated *massive* in preference to *eruptive* because the former term was considered free from expression of any genetic idea. In this second edition, while advocating the genetic basis of classifica-

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[1] "Die Erkenntniss dieses Verhältnisses machte die neue Auflage dieses Buches zu einer Neubearbeitung. Der Zweck derselben wird erreicht sein, wenn es mir gelungen ist, dieser Grundanschauung eine allgemeinere Anerkennung zu verschaffen und darzuthun, dass die Gesteinsstructur das sicherste und ausgiebigste Mittel zum Aufbau eines natürlichen Systems der Gesteine an die Hand giebt."

tion as all important, Rosenbusch retains the group term *massive*, yet in both works it is clearly the igneous origin which is first in mind and which is recognized as of prime importance in producing rock structure, chosen as the leading factor in constructing the new system.

After having stated his belief that rock structure is the best basis of classification of "massive rocks" Rosenbusch proposed to divide them into three groups: (1) Deep-seated rocks ("Tiefengesteine"), (2) Dike rocks ("Ganggesteine"), and (3) Effusive rocks ("Ergussgesteine"). The critic is obliged to point out that this proposition is inconsequent, for not only is structure not expressed in the terms chosen, but another distinct factor is expressed, namely, mode of occurrence. The further development of Rosenbusch's scheme makes it clear that he did not intend to emphasize the actual facts of geological occurrence, plainly as he stated them, but rather to express in this way his conception of the genesis of structure. Recognizing that different structures result from the consolidation of a given magma according to the attendant conditions, Rosenbusch selected the geological factor appearing to him of greatest influence among many conditions and made that the expressed basis of structural classification. Since simplicity and logical directness are surely of utmost importance in systematic constructions the unnecessary indirectness of this proposition may be designated a fatal weakness. Furthermore, the geologist is warranted in objecting to it because the expressed division of igneous rocks is one which he has used in the past and must use in the future, in its literal and appropriate sense, quite apart from the idea hidden in the terms of Rosenbusch's system.

To the above noted criticisms of Rosenbusch's first application of structure in classification must be added another, based upon the fact that the division of *Dike rocks* was not in reality provided for rocks occurring in dikes, but for a group of rocks for which Rosenbusch assumed a certain genesis. An hypothesis of magmatic differentiation and assumptions of limited occurrence and of characteristic structure are all involved in the discrimination of the group named "Dike rocks." In this light this group is certainly not co-ordinate with the other two of the same rank as defined.

In the subdivision of the three classes of "Massive rocks" Rosenbusch applied mineral composition as a factor, producing Families. The quantitative composition, either chemical or mineral, received no expression, so that, for example, anorthosite and the most highly pyroxenic gabbro or norite are found together in the gabbro family. Moreover in the porphyritic Dike rocks only the phenocrysts are considered in determining the systematic position of a given rock. Thus a porphyry having the chemical composition of a granite is referred to syenite-porphyry in case its excess of silica chances to be confined to the groundmass, while had quartz phenocrysts been present it would have been called granite-porphyry. In the Effusive rocks, Rosenbusch hesitates to apply the same rule consistently. The families of these rocks are defined in very general terms as the "equivalents" of certain granular rocks and described as containing certain phenocrysts in a groundmass of variable appearance.

As in the earlier system, all feldspar-free rocks of the deep-seated class are united as Peridotites. The peculiar character of the Dike rocks as a division not co-ordinate or co-extensive in range with the Deep-seated or Effusive rocks appears in the fact that mineralogical groups corresponding to the granites, syenites, and diorites, only, are recognized.

Geological age is acknowledged by Rosenbusch to have been assigned a higher value in classification than belongs to it, but it is retained, in the Effusive class, and the use of duplicate terms perpetuated.

*H. Rosenbusch, 1896.*—The third edition of the "*Mikroskopische Physiographie der massigen Gesteine,*" issued in 1896, contains no essentially new systematic features. The principles above set forth are reaffirmed, and, save for the elaborated discussions of magmatic differentiation, which show more plainly than in the preceding edition the strong influence of hypothetical considerations in giving form to this system, there is little of note to comment upon in this place. In discussing the essential characters of the three groups of Dike rocks, Rosenbusch brings out more forcibly than before the genetic idea really lying at the base of the distinction of the Dike rock class. In connection with the discussion of the Dike rocks it is suggested that a further class may be necessary to include the intrusive rocks of sheets and laccoliths which seem to him to possess distinctive structures.

That the system of Rosenbusch does not result in a consistent and logical classification of igneous rocks is abundantly illustrated by numerous instances, many of them freely acknowledged by the author. The family of the diabase rocks furnishes one of the most notable cases. In 1887 these rocks were classified with the deep-seated rocks, although many of them were known to be effusive; in 1896 the same rocks are placed with the effusives, with the statement that many are intrusive. Placed in the effusive class, they are acknowledged to be partly of older and partly of younger age, but no age distinction is thought to be practicable.

*Justus Roth, 1883.*—Shortly before Rosenbusch issued the second edition of his *Physiographie*, there appeared a complete systematic discussion of rocks by Justus Roth, in the second volume of his *General and Chemical Geology.*[1] Petrography is defined by Roth as the science of the mode of origin, constitution, and alteration of rocks; *i. e.*, the petrology of many English and American writers. In introducing the systematic descriptive part of the subject, Roth remarks: "The difficulty in constructing a system of rocks is completely expressed in the term *aggregate*, and thereby all recourse to genera and species is prohibited."[2] From the nature of rocks and the conditions of

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[1] *Allgemeine und chemische Geologie;* Zweiter Band, "Petrographie" (Berlin, 1883-1885), pp. X + 695.

[2] "Die Schwierigkeit der Systematik der Gesteine ist durch die Bezeichnung Aggregat vollständig ausgedrückt und damit alle Anlehnung an Gattungen und Species ausgeschlossen," *loc. cit.*, p. 41.

their origin, he thinks that every system must so largely represent individual opinion that probably no one system can ever receive universal recognition.

The systematic arrangement of Roth is, in its general outline, as follows:

A. Rocks composed essentially of minerals.
  I. Plutonic (consolidation products of molten magmas). Free from fossils, composed of minerals or substance chemically like a mineral aggregate.
    1. Eruptive. (Breaking through other rocks.)
      *a.* Pre-Tertiary.
      *b.* Post-Cretaceous.
        Appendices to *a* and *b* contain rocks produced by weathering. Tuffs.
    2. Crystalline schists.
      Appendix-Weathering products.
  II. Neptunic.
    1. Partly fossiliferous; composed of minerals and of the products of the decay, decomposition, and attrition of minerals.
      *a.* Precipitates from solution.
      *b.* Deposits from suspension.
    2. Clastic, composed of rock fragments.
B. Rocks composed essentially of organic remains.
C. Products of contact metamorphism.

It will be observed that the ancient crystalline schists are regarded as the primary crust of consolidation of the earth.

The geological factors of origin, relations, or age, are variously applied in the construction of this scheme, and in constitution the distinction between mineral and rock particles is made. All Plutonic rocks are regarded as consisting essentially of silica or *silicates*, excepting that in the crystalline schists *carbonates* appear. The silica free minerals—apatite, magnetite, ilmenite, etc., are treated as accessory constituents. This exclusion of the latter group of minerals from a position of systematic importance is not discussed by Roth, but its evident result is that in certain rocks, *e. g.*, those rich in magnetite, the components do not have their natural and logical weight in classification.

Of the pre-Tertiary eruptive rocks, Roth makes, for convenience, three divisions:

I. Orthoclase rocks.
II. Plagioclase rocks.
III. Peridotites.

The first two of these groups should, logically, have been united systematically in the division of Feldspathic rocks, including all with appreciable content in feldspar, since the Peridotites are defined as free, or nearly free, from feldspar. The question of recognizing the quantitative relations of mineral constituents is not mentioned by Roth.

The silicate minerals are applied by Roth for the subdivision of the three main groups in the usual way, and by means of *structure* the granular, porphyritic, and glassy varieties are distinguished.

In the detailed treatment of Eruptive rocks, as in the arrangement of Crystalline schists, the Neptunic rocks and the Classes B and C, mentioned above, Roth's order of presentation and discussion can hardly be said to be systematic. It is an arrangement for convenience of description, not based upon the logical application of principles; and it is, therefore, not desirable to devote more space to its analysis in this review.

*E. Kalkowsky, 1886.*—A condensed text-book on rocks was published by E. Kalkowsky, in 1886, with the title *Elemente der Lithologie.*[1] For the primary division of rocks the author formulates an original criterion, and proposes two great classes:

I. "Anogene"—of which the material came to the place of rock formation from *below.*
II. "Katogene"—of which the material was derived from *above.*

These correspond closely to the eruptive and sedimentary divisions of other authors.

For the classification of the "Anogene" rocks Kalkowsky applies the following factors: (1) Chemical composition as represented in mineral composition; (2) the usual age distinction; (3) structure. He rejects genetic distinctions as unsuit-

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[1] Heidelberg, 1886, pp. 316.

able. In detail Kalkowsky's scheme is similar in its results to that of Zirkel, but, as he does not define his smaller rock divisions, a further discussion of his arrangement seems unnecessary. The definitions are omitted, according to the author, because the student must learn to know the rocks by the study of named hand specimens and will, therefore, find out what they are without definitions.

*J. J. Harris Teall, 1886, 1888.*—The most extensive treatise on rocks thus far published in England is the descriptive work *British Petrography*, by J. J. Harris Teall, issued almost simultaneously with the second edition of Rosenbusch's *Massige Gesteine*. This work lays no claim to being a systematic petrography, and describes almost exclusively the igneous class; but from its scope a discussion of principles of rock classification was necessary, as explanatory of the arrangement actually used. Teall considers rocks so complex and indefinite in character that in the existing state of knowledge no true systematic arrangement is possible. His order of presentation is, in fact, one of convenience, and does not express his own views of the most natural basis of classification.

In discussion of principles, Teall points out that chemical composition, as the constant and primary character of igneous rocks, is the natural basis of classification and in accordance with the Bunsen law of two magmas. He, however, does not work out any new proposition to use chemical composition. The arrangement under which rocks are described is a mixture of the methods of Rosenbusch and Michel-Lévy. All igneous rocks are placed in seven groups, as follows:

*A.* Rocks composed of the ferro-magnesian minerals: olivine, enstatite, augite, hornblende, and biotite. Feldspar absent; or, if present, occurring only as an accessory constituent.

*B.* Rocks in which plagioclase is the dominating feldspathic constituent. Nepheline and leucite absent. Orthoclase is frequently present.

*C.* Rocks in which orthoclase is abundant. Plagioclase usually present. Nepheline and leucite absent.

*D.* Rocks containing nepheline or leucite; sometimes nepheline and leucite.

*E*. Rocks not included in any of the preceding groups.
*F*. Vitreous rocks.
*G*. Fragmental volcanic rocks.

It will be seen that this grouping is mainly mineralogical and does not express the quantitative element in any logical way. It practically recognizes the entrance of feldspar, in any amount above that of the undefined "accessory" rôle, as creating a large group of *feldspathic rocks*. The subdivision of these groups is first on some further mineral distinction and after that occurrence and texture enter combined into the system by distinguishing rocks of *granitic* from those of *trachytic* texture, using these terms in the sense of Fouqué and Michel-Lévy, and conceiving that the result is practically to separate *plutonic* or deep-seated from *volcanic* or effusive rocks. Age is not introduced as a factor.

Within the last twenty years several attempts have been made to apply, *in extenso*, the chemical composition of rocks for their classification. These attempts have been prompted by various motives. Some appear to have no really practical object, viewed from the petrographer's standpoint; others are connected with hypotheses of magmatic differentiation; and still others have been inspired by a realization of the complexity of the problem of a rational arrangement of rocks on the basis of their numerous and highly variable mineral constituents. It appears to the writer, however, that it may be fairly said of all these attempts that they are either not classifications of *rocks*, or that they are not actually *chemical* classifications.

*Franz Schröckenstein, 1886, 1897.*—Two peculiar attempts by Franz Schröckenstein, an Austrian writer, to discuss the chemical composition of silicate rocks, irrespective of their origin, and upon that basis to classify them, are mentioned here only for the sake of completeness, as these attempts have no direct bearing upon a logical system of rocks. The writer has seen only the more recent of the essays in question,[1] depending for the

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[1] "Silicat-Gesteine und Meteorite," *Petrographisch-chemische Studie auf Grundlage des neuesten Standes der Wissenschaft bearbeitet.* Prag, 1897.

earlier one[1] upon the summary given by F. Loewinson-Lessing.[2]

Schröckenstein's view of igneous rocks will, on account of its fantastic imaginings, impress many a reader as belonging rather to the eighteenth, or a still earlier, century, than to the close of the nineteenth ; and, although his propositions are of no consequence to petrography, the fact that they have been put forth at all, in the very last decade of the period in review, has a certain melancholy interest.

Schröckenstein considers the original crust of the earth to have been a *silicate of alumina*, probably with excess of silica. This simple primary magma is conceived to have been first rendered impure by meteoric showers, introducing lime, magnesia, and iron. At a later period the alkalies and water were precipitated from the atmosphere. The alkalies are considered as of very subordinate (" nebensachlich ") importance and the chemical problem of rocks, as the author views it, is to compare the relative amounts of the original alumina silicate and the meteoric impurities. That is to say, *the author proposes classes according to the degree of adulteration of the original magma and orders according to the character of the adulterant.*

The method followed by Schröckenstein in comparing analyses of silicate rocks appears to be somewhat as follows:

First, magnetite is calculated out, as an *extraneous substance*, whenever the analysis is sufficiently modern, through determinations of both ferric and ferrous oxides, to give a basis for such calculation. When the analysis is inadequate and the iron is lumped under one or the other oxide, the result is accepted by the author and $Fe_2O_3$ is supposed to replace alumina or FeO is added to MgO and CaO. Not until magnetite is deducted does Schröckenstein consider that the real rock is under discussion. Inasmuch as he states that after deducting magnetite there is either no iron left or but one oxide appears, it is evident that the

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[1] Ausflüge auf das Feld der Geologie," *Geologisch-chemische Studie der Silicatgesteine*, II Auflage, Wien, 1886.

[2] " Studien ueber die Eruptivgesteine," *Compte-Rendu, VII Cong. Géol. Internat.*, 1899, p. 196.

maximum possible amount of magnetite is deducted. The remainder is then calculated to 100. The analyses are not given in their original form.

The systematic plan of Schröckenstein consists, in his later publication, in establishing five classes of silicate rocks, according to the relations of $Al_2O_3$ to RO ($=CaO + MgO + FeO$) as shown by the *percentages* of the calculated remainder after deducting magnetite.

$$\text{I. } \frac{RO}{Al_2O_3} < \frac{1}{4}; \quad \text{II. } \frac{RO}{Al_2O_3} < \frac{1}{2} > \frac{1}{4}; \quad \text{III. } \frac{RO}{Al_2O_3} < \frac{3}{4} > \frac{1}{2};$$

$$\text{IV. } \frac{RO}{Al_2O_3} < \frac{1}{1} > \frac{3}{4}; \quad \text{V. } \frac{RO}{Al_2O_3} > \frac{1}{1}.$$

Two orders appear under each class according as lime or magnesia dominates.

Although Schröckenstein professes to use the latest information, as stated in the title of his recent publication, his results are based upon the discussion of 340 analyses, many of them old, while on the other hand no single one of the hundreds of analyses made in the laboratory of the United States Geological Survey, within the past twenty years, is utilized. Hundreds of European analyses of recent date are also ignored.

It seems unnecessary to give any further details concerning Schröckenstein's propositions. He is not actually treating rocks and his superficial considerations of chemical composition can have no bearing upon true petrographic system.

*H. O. Lang, 1891.*—An attempted arrangement of igneous rocks on a chemical basis by H. O. Lang,[1] in 1891, is founded on the idea that since the feldspars are the most important constituents of eruptive rocks, an appropriate and practical chemical basis of classification may be found in the relations of the bases potash, soda, and lime, the distinctive elements of the various species of feldspar. In one case Lang used the percentage

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[1] "Versuch einer Ordnung der Eruptivgesteine nach ihrem chemischen Bestande," *Tscher. Min. Pet. Mitth.*, XII, 1891, p. 199.

"Das Mengenverhältniss von Calcium, Natrium, und Kalium als Vergleichungspunkt und Ordnungsmittel der Eruptivgesteine," *Bull. Soc. Belge de Géol.*, 1891, V, p. 123.

amounts of the oxides found by analysis, and in the other the amounts of the elements potassium, sodium, and calcium. Here again is the situation that only a part of some rocks is actually under discussion, and the result can be of no real value to petrography.

*F. Loewinson-Lessing*, 1890, 1897. In 1890 an attempt at a chemical classification of igneous rocks was made by F. Loewinson-Lessing,[1] based upon the quantitative relations of silica to the various oxides of the bases, grouped under $R_2O$, $RO$, and $R_2O_3$, as shown in *percentages* by bulk analysis. By means of empyrical formulæ the author thought to find a way of expressing regular relationships supposed to exist between the silica contents and the various oxide groups. Rocks exhibiting the following simple relationships were designated *types*, I to V being the principal ones, and VI to IX intermediate:

$$\begin{array}{c}\text{Acid}\\\text{Rocks}\end{array}\left\{\begin{array}{l}\text{I. } SiO_2 = 2(R_2O + RO) + R_2O_3 + Q\ . \\ \quad\text{VI. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3 + Q\ .\end{array}\right.$$

$$\begin{array}{c}\text{Neutral}\\\text{Rocks}\end{array}\left\{\begin{array}{l}\text{II. } SiO_2 = 2(R_2O + RO) + R_2O_3\left(\text{II} = \frac{\text{I} + \text{IV}}{2}\right)\ . \\ \quad\text{VII. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3\ .\end{array}\right.$$

$$\begin{array}{c}\text{Basic}\\\text{Rocks}\end{array}\left\{\begin{array}{l}\text{III. } SiO_2 = R_2O + RO + R_2O_3\left(\text{III} = \frac{\text{II} + \text{IV}}{2}\right)\ . \\ \quad\text{VIII. } SiO_2 = R_2O + RO + \frac{1}{2}R_2O_3\left(\text{VIII} = \frac{\text{III} + \text{IV}}{2}\right)\ .\end{array}\right.$$

$$\begin{array}{c}\text{Ultra}\\\text{Basic}\\\text{Rocks}\end{array}\left\{\begin{array}{l}\text{IV. } SiO_2 = \text{or} < RO\ . \\ \quad\text{IX. } SiO_2 = \frac{1}{2}RO\ . \\ \text{V. } SiO_2 = O\ .\end{array}\right.$$

Since percentages instead of molecular ratios were used, the simple relations here adopted have no real significance as expressing a regular connection between chemical and mineral composition. This fault was perceived by the author and cor-

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[1] "Étude sur la composition chimique des roches éruptives," *Bull. Soc. Belge de Géol.*, 1890, IV, Mem., p. 221.

rected in the publication to be discussed below. These so-called types were assumed by Loewinson-Lessing to correspond more or less closely to certain commonly known rock groups.

The more elaborate discussion of the chemical relationships of igneous rocks by Loewinson-Lessing, presented to the International Geological Congress at St. Petersburg, in 1897, and published two years later in the *Compte-Rendu*, deserves somewhat fuller consideration.[1] A brief statement of the author's point of view is desirable before explaining the system proposed.

In reviewing the applicability of various factors in producing a rational system, Loewinson-Lessing asserts that the mineral composition of a rock is a function of its chemical composition. The exceptions to this rule admitted by him are of little importance. Then follows the further statement that the principle or characteristic of mineral composition as a basis of classification is faulty and unsatisfactory because it does not show the relative abundance of the minerals in the various rocks. That is, however, as it appears to the writer, not the fault of the *principle*, but of the manner in which it has been applied in existing systems. If mineral composition is a function of the chemical composition, it is just as capable of expressing the constitutional relations of rocks as the latter, if properly used. The real objection to its application in the quantitative way, necessary to this expression, is simply one of practicability. The problem is too complex.

As for his own system, Loewinson-Lessing starts from the idea that eruptive rocks may be considered as *silicate rocks* and classified as such. Whatever the facts as to predominance of silicates in these rocks may be, it seems to the writer that this conception is not complete as to its basis of fact, and is thus inadequate to serve as a means of classification. Further fundamental propositions enunciated by the author are that: (1) silicate rocks should be classified by the same artificial means as the silicates themselves; (2) while rocks are not stoichiometric

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[1] F. LOEWINSON-LESSING, "Studien über die Eruptivgesteine," *Compte-Rendu de la VII session du Congrès Géologique International, Russie,* 1897, pp. 193–467.

compounds, they are not accidental mixtures; (3) one must consider the relative amounts of *all* oxides of bases to each other and to silica; (4) as silica is the dominant constituent it is proper to take it as the basis for the primary classification; (5) the next factor to be applied must be the contents in the three oxide groups, alkalies, alkaline earths, and the sesquioxides; (6) various single oxides may be used for further subdivisions. From this statement it might be supposed that a classification created by the successive use of the chemical factors named was to be set up by Loewinson-Lessing, and such an arrangement of magmas would have claim to being a chemical classification. But the author does not do that, as we shall see.

The actual system proposed by Loewinson-Lessing is to use the silica contents for the formation of four general groups: (1) Acid rocks; (2) Neutral rocks; (3) Basic rocks; (4) Ultra-basic rocks.

The second division is obtained by taking a certain number of analyses representing known rock families (established on the unsatisfactory basis of mineral composition) and determining the *mean* of these analyses, which is then set up as the composition of a rock *type*, and its formula and coefficient of acidity are ascertained.

It is clear that the grist of this mill depends entirely upon what is put into the hopper. It is not a chemical classification but a chemical *characterization* of mineralogical rock groups arbitrarily selected by the author. It will, of course, be possible to secure means corresponding to any formula desired as a type, and the rocks thus having typical position could be adopted as centerpoints of groups or families. For the ordinary range of rocks these types would often coincide with recognized rocks, assigned certain names in existing systems, and these names might then be given by redefinition to the families thus indicated. But what would be the purpose of such a scheme? It could not express the existing relations between the mineral composition of the rock and the chemical constitution of the magma.

*A. Osann, 1900, 1901.*—A further attempt to utilize chemical composition as a factor in the classification of igneous rocks was made by A. Osann in the closing year of the century. Under the title "Versuch einer chemischen classification der Eruptivgesteine "[1] Osann essays to use chemical composition as a supplement to mineral and textural characters, by establishing various chemical types within rock families formed upon the Rosenbusch system. The author accepts the classes of deep-seated, dike and effusive rocks, in the Rosenbusch sense, and the vaguely defined families established upon mineral composition. Realizing that by this latter factor, as currently applied, the relative abundance of the minerals is not sufficiently taken into account, Osann attempts to bring out quantitative relations, within the families, by establishing certain types upon the basis of chemical composition.[2]

It is clear that if the quantitative element was not sufficiently expressed in forming the families discussed by Osann, he fails to remedy the defect. A logical subdivision of the families on a chemical basis would principally serve to point out the defects in this respect, and would really weaken rather than strengthen the system as a whole.

But the "types" set up by Osann are in no sense systematic divisions of the families. The "type" of this author is simply a chosen well-analyzed rock, differing in chemical composition from other rocks within its family, according to the adopted method of comparison. To a type thus established are referred other rocks of nearly identical chemical characters. But the types bear no definite relation to each other or to the family.

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[1] *Tschermak*'s *Min. und petr. Mittheilungen*, Bd. XIX, 1900, pp. 351–469, and Bd. XX, 1901, pp. 399–558.

[2] The author's standpoint may be sufficiently understood from the following statement: "Der Hauptmissstand der mineralogisch-structurellen Classification liegt darin, dass dem relativen Mengenverhältniss der wesentlichen Gemengtheile zu wenig Bedeutung zuerkännt wird, und es wird gerade die Hauptaufgabe der chemischen sein, in dieser Richtung ergänzend und vertiefend zu wirken." "So kann es sich bei dem hier unternommenen Versuch ebenfalls nur um ein künstliches System handeln, welches in erster Linie dazu bestimmt ist, das mineralogisch-structurelle zu ergänzen." *Ibid*, Bd. XIX, pp. 351–352.

They merely serve to show the chemical range found within the families so far as Osann's examination extends.

From the above statement it would appear that Osann has not, in reality, proposed a chemical classification in the systematic sense, and hence it is not desirable to enter further into the analysis of this elaborate discussion of the chemical varieties represented within the families of the Rosenbusch system.

This discussion of petrographic systems proposed during the nineteenth century will close with a review of three attempts to bring all known rocks into orderly arrangement. Not that the authors think to have formulated natural or logical systems, for that is expressly disclaimed by them. Yet in presenting these comprehensive arrangements of rocks, according to the light of the last decade of the century, these authors define and illustrate in a most effective way the present condition of systematic petrography.

*Ferdinand Zirkel, 1893, 1894.*—The second edition of Zirkel's *Lehrbuch der Petrographie* is the most comprehensive and complete description of all known rocks ever published, and it therefore represents the present status of the systematic science as a whole, better than any other work, and hence deserves careful consideration. But the fact staring the student in the face is that systematic petrography is still very largely an arrangement for convenience of description, and is not, in its entirety, a logical expression of relationships. Within the division of igneous rocks there is at least some attempt at system, but the other rocks confessedly defy logical treatment by any method as yet proposed.

The primary division of all rocks is on general geological grounds into four groups:

I. Igneous rocks—"Massige, eruptive Erstarrungsgesteine."
II. Crystalline schists.
III. Sedimentary crystalline rocks (not clastic.)
IV. Clastic rocks.

This division is clearly based on geological considerations, and is chosen in place of the primary arrangement of the first edition because, as Zirkel points out, of inconsistencies and unnatural associations which resulted, some of which have been mentioned in this review. Contact metamorphic rocks are treated in connection with the igneous rocks which produced them Fragmental igneous rocks are placed with the clastics.

In the systematic classification of igneous rocks Zirkel uses the bases of arrangement in the following order: (1) mineral composition; (2) structure; (3) age. The availability of chemical composition, alone, or in expressed combination with mineral constitution, is not discussed. The method of applying mineral composition for the classification of igneous rocks is that commonly used. Concerning this Zirkel remarks:

> In a mineralogical arrangement of massive rocks the following considerations are at present determinative: In the great majority of these rocks feldspars and other silicates resembling feldspars (such as nephelite, leucite, melilite) play the chief rôle, and therefore it is most natural to base the classification of such rocks upon the nature of these minerals, in accordance with existing nomenclature.[1]

This procedure results in placing *feldspar- or feldspathoid-bearing* rocks in one large group opposed to *feldspar-free* rocks. Whatever the facts may be as to the relative quantitative importance of different minerals in igneous rocks, it is clearly arbitrary to concede to any mineral the "principal rôle" where it is far subordinate to others. The result is a qualitative expression of mineral composition, bringing chemically unlike rocks together in many divisions.

In the descriptive portion of the *Lehrbuch*, igneous rocks are grouped under seven heads :

I. Rocks with alkali feldspar and quartz or excess of silica.

II. Rocks with alkali feldspar, without quartz or excess of silica, without nephelite or leucite.

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[1] Für die mineralogische Gruppirung der Massengesteine sind zur Zeit folgende Erwägungen maassgebend : In der weitaus allergrössten Mehrzahl derselben spielen Feldspathe und andere feldspathähnliche Silicate (wie Nephelin, Leucit, Melilith) eine Hauptrolle und so scheint es am natürlichsten, die Classification der hierher gehörigen Gesteine auf die Natur dieser Mineralien zu begründen, was zugleich der bestehenden Nomenclatur entspricht. — *Petrographie*, Band I, p. 832.

III. Rocks with alkali feldspar, without quartz or excess of silica, with nephelite (haüynite) or leucite.

IV. Rocks with lime-soda feldspar, without nephelite or leucite.

V. Rocks with lime-soda feldspar and nephelite or leucite.

VI. Rocks without true feldspars, but with nephelite, leucite, or melilite.

VII. Rocks without either feldspars or feldspathoid.

Structure and geological age are applied by Zirkel under each of the mineralogical groups, as follows:

- Granular rocks.
  - (No distinctions by age.)
- Porphyritic and glassy rocks.
  - Pre-Tertiary.
  - Tertiary and recent.

The structural distinction is clearly in fact between (1) granular and (2) non-granular, the range in structure within the second division being by no means covered by the two terms porphyritic and glassy.

The use of age as a factor in classification of "porphyritic and glassy rocks" while it is not applied to the granular rocks is apparently more a recognition of the usage of the time, by which a duplicate set of terms has been provided for effusive rocks, than of any definite principle. The task of reconstructing the nomenclature of the science is still one from which the systematic petrographer shrinks.

The group of the *crystalline schists* established by Zirkel is not founded upon definitely stated principles, and is therefore not a systematic group. It is defined by enumeration of things belonging in it or excluded from it, and must be treated as a convenient expedient for purposes of rock description. But although this is true the crystalline schist group of Zirkel is no more unsystematic than the assemblages of other petrographers given the same name. It is then germane to the present discussion to state the actual course adopted in the *Lehrbuch*.

Zirkel includes in his group of the crystalline schists, and as its most important element, the pre-sedimentary gneisses, schists, etc., which cannot be inferred from their attitude to other rocks to be of igneous origin. Included with these are all rocks of the same texture and composition demonstrably derived from sediments or occurring intercalated in the sedimentary series but not clearly of igneous origin. Excluded from the group under discussion are the primarily banded igneous rocks and the metamorphic derivatives of igneous rocks whenever that origin can be established, and whatever the process of change may have been. In other words the group includes the rocks below the oldest known sediments so far as they are not visibly eruptive or igneous and all later rocks of the same characters derived from sediments or of unknown origin.

This group then has nothing in texture or composition to distinguish it. Neither of the elements of the name has any restrictive significance. The group is geologically homogeneous only in case the schists of unknown origin are actually derived from sediments. If, as many suppose, a large proportion of the Archean gneisses, etc., represent igneous masses, metamorphosed or not, the group is not only heterogeneous from the genetic standpoint but causes the separation of identical things.

In the subdivision of the crystalline schists mineral composition is applied, the predominant constituent causing the reference of a rock to a certain group. The terms gneiss and schist are not defined.

The group of *crystalline, or non-clastic sedimentary rocks,* is heterogeneous in constitution as is apparent from a partial list of the rocks referred to it : ice, cryolite, limestone, opal, quartzite, porphyroid, iron ores, coals, diatomaceous earth. That such a group lacks the unity required in a systematic division, and that its descriptive name by no means covers the case, is apparent at once. It is confessedly a grouping for convenience only, and embraces, in fact, the remaining rocks after the other three have been established.

*H. Rosenbusch, 1898.*— A comprehensive discussion of rocks was issued in 1898, by H. Rosenbusch, entitled, *Die Elemente der Gesteinslehre.*[1] Although much less detailed than the *Lehrbuch* of Zirkel, this work is of much interest as expressing the views of

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[1] Stuttgart, 1898, pp. 546 + 4.

one of the great German masters, almost at the close of the century.

Rosenbusch's primary division of rocks is into four great classes:

I. Eruptive rocks ("Eruptivgesteine").
II. Stratified rocks ("Die schichtigen Gesteine").
III. Crystalline schists.
IV. Primary crust of the earth ("Erste Erstarrungskruste").

Concerning the first class, it is to be noted that Rosenbusch drops the term "massig," used for twenty-five years, as less appropriate—"weniger passend villeicht"—than *Eruptive.* In the further treatment of eruptive rocks Rosenbusch does not depart from the principles and methods of the last edition of the "*Physiographie der massigen Gesteine,*" and there is, therefore, no occasion to repeat the analysis of that work already given.

*The stratified rocks* of Rosenbusch form a class under the general idea expressed by Lossen. It is pointed out by Rosenbusch that the character of the materials of stratified rocks is not so intimately related to the essence ("*Wesen*") of the mass as with eruptive rocks, and hence there is no corresponding firm basis for their classification.

Stratified rocks are divided into seven families, as follows:

1. *Precipitates*—including rock salt, gypsum, anhydrite, barite, etc.
2. *Psephites and Psammites* or clastic rocks.
3. *Siliceous rocks*—not clastic, partly chemical deposits, partly organic, partly of undetermined origin, *e. g.*, lydite, diatomaceous earth, sinter, etc.
4. *Carbonate rocks*—including limestone, dolomite, and impure calcareous rocks, loess, etc.
5. *Iron rocks*—including spathic iron, spherosiderite, brown hematite, bog ore, etc.
6. *Clay rocks*—including clay, clay-slate, phyllite, etc.
7. *Porphyroid.*

*Appendix.* Coals, etc.

In this arrangement Rosenbusch attempts no logical construction of anything which can be called a system. As he frankly admits, the porphyroids are metamorphic rocks, often associated with the crystalline schists, and as they were not derived from sediments it is incorrect to place them in the stratified class. In the necessity for placing coals and other carbonaceous rocks in an *appendix* is further evidence that the arrangement under discussion is inadequate.

*The Crystalline Schists* are defined by Rosenbusch as alteration products of eruptive or sedimentary rocks. Both dynamic and contact metamorphism are recognized as effective in producing them. Rosenbusch further asserts that the changes have been entirely structural and molecular, and not chemical, hence by quantitative analysis of a metamorphic or crystalline schist one may arrive at a knowledge of the composition of the original rock, eruptive or sedimentary, from which that schist was derived. The designation *metamorphic rocks* is acknowledged to be appropriate.

The Crystalline Schists are treated under the following heads: (1) Gneiss, (2) Mica schist, (3) Talc schist, (4) Chlorite schist, (5) Amphibole and pyroxene rocks, (6) Serpentine, (7) Lime series, (8) Magnesian series, (9) Iron series, (10) Emery.

Concerning these groups Rosenbusch remarks:

> In most of these large groups of the Crystalline Schists, which are held together mainly through mineral composition, there are united rocks of fundamentally different genesis. Therefore they are not natural but rather artificial series. For the replacement of these artificial groups by natural ones there is lacking, at the present time, both necessary breadth of experience and maturity of judgment, from which the need for reform in various directions is evident.[1]

Believing that the natural classification of metamorphic rocks must develop by the historical method, with the increase of knowledge, Rosenbusch proposes, as a step in the desired direction, to apply the prefix *ortho* to the names of gneisses derived

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[1] In den meisten dieser grossen Gruppen von Krystallinischen Schiefern, welche lediglich durch gleichen oder ähnlichen Mineralbestand zusammengehalten werden, sind genetisch grundverschiedene Gesteine zusammengefasst. Daher sind sie nicht natürliche sondern künstliche Reihen. Zur Umgestaltung dieser künstlichen Gruppen in natürliche fehlt zur Zeit noch einerseits die erforderliche Breite der Erfahrung, andererseits die Reife des Urtheils und damit das Bedürfniss nach Reform in weiteren Kreisen.—*Elemente*, p. 461.

from eruptive rocks, and *para* to those derived from sediments. The enumerated divisions of Crystalline Schists are not defined in a systematic manner, and even the terms *gneiss* and *schist* are given no definite meaning.

The fourth class of rocks advocated by Rosenbusch, on genetic grounds, *the original crustal rocks*, is considered by him as not certainly represented by any known rocks. But it appears to him probable that they possess the habit of the crystalline schists.

*Johannes Walther, 1897.*—An outline of a general classification of rocks upon a logical and consequent basis was presented to the Seventh International Congress of Geologists in St. Petersburg, in 1897, by Johannes Walther.[1] Although but an outline of a system this proposition deserves attention as the most consistent effort yet made to formulate a system of petrography co-ordinate in method for different classes of rocks.

Walther starts from the consideration that the growth of petrographic system in recent years has been very one-sided, a fact recognized by all. He believes that a natural arrangement of igneous rocks has been provided by petrographers of the modern school, while sedimentary and metamorphic rocks are still arranged upon old and partly incorrect bases. Aiming to secure a logical system, Walther formulates the following principles which he thinks should be observed in the classification of rocks:

I. The petrogenesis of recent deposits and the direct observation of actual processes are the fundamental principles of classification.

II. Every older rock has *primary* characters given it at its formation, and secondary ones derived by *diagenesis* or *metamorphosis*.

III. The derived characters may so change the type of the rock as to become "essential," while the primary characters become "accessory."

IV. In spite of this last condition only the primary characters should determine the principal groups of petrographic system.

V. Next to the primary lithologic characters the primary form of occurrence has a classificatory value. There must be distinguished, therefore, Unstratified, Stratified, and Dike rocks.

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[1] "Congrès géologique international," *Compte-Rendu de la VII session, St. Pétersbourg, 1897*, p. 9 (issued in 1899).

VI. The characters derived by chemical diagenesis, or by contact and pressure metamorphism, serve for distinction of lesser groups.

VII. The altered rocks are to be placed with their original types.

The system proposed by Walther, in accordance with the stated rules, is in outline the following:

I. Mechanical Rocks. Composed of older rock fragments; divided by form and size of the fragments into 5 subgroups:
  1. Breccias: (*a*) Unstratified; (*b*) Stratified; (*c*) Dike form.
  2. Conglomerates: (*a*) Stream deposits; (*b*) Delta deposits; (*c*) Strand deposits.
  3. Moraines.
  4. Psammites — sands, more or less sorted: (*a*) Quartzose sandstone; (*b*) Arkose; (*c*) Olivine sands; (*d*) Iron ore sands, etc.
  5. Pelites — of minute particles: (*a*) Unstratified; (*b*) Stratified — fresh-water; (*c*) Stratified — marine.

II. Chemical rocks. Precipitates or sublimates.
  1. Calcium carbonate.
  2. Calcium sulphate.
  3. Sodium chloride.
  4. Haloid Salts ("Abraumsalze").
  5. Silica.
  6. Carbon.
  7. Ores.

Further divisions are made by occurrence — as Stratified, Unstratified, or in Dikes.

III. Organic rocks. Formed of the remains of animals or plants.
  1. Limestone: (*a*) Unstratified — Reef limestone; (*b*) Stratified — derived from plants (algæ); (*c*) Stratified — derived from animals.
  2. Silica: (*a*) Diatomaceous earth and land plants; (*b*) Diatomaceous earth with marine fossils; (*c*) Radiolarian earth.

IV. Volcanic rocks — Consolidated magmas.
  1. Lavas — Compact rocks: (*a*) Unstratified — deep-seated rocks; (*b*) Stratified — Effusive rocks; (*c*) Dike rocks.
  2. Tuffs — Magmas consolidated in small fragments: (*a*) Unstratified, in streams, not sorted; (*b*) Unstratified, subaqueous accumulations near vent — water tuffs; (*c*) Stratified, sorted according to specific gravity; originally inclined; traversed by dikes — tuffs about a land volcano; dry tuffs; (*d*) Stratified, alternating with marine deposits, without dikes; tuffs of sedimentation; (*e*) tuff dikes or chimneys.

In connection with these primary rocks the author mentions, as examples, many of the forms derived from them by diagenesis or metamorphosis, but does not outline the system for discriminating and naming these alteration products. Some of the metamorphic rocks, such as gneiss and mica schist, may be formed from several primary rocks.

The proposition made by Walther is manifestly rather the work of a geologist than of a petrographer (as was pointed out by Brögger in discussion, when it was presented to the Congress). Like many discussions of principles concerned in the systematic problem, it is not sufficiently worked out to show a practical result, and does not fully test the adaptability of the chosen factors for petrographic system. But it seems to the writer that in this renewing of effort to treat the non-igneous rocks in logical systematic manner lies ground for hope that something more than an arrangement for convenience may develop during the early years of the twentieth century.

Returning to a consideration of the principles adopted by Walther, it may be remarked that the first one would be excellent if the processes of rock formation were all open to examination. Unfortunately, they are not so, in all cases. Many igneous rocks and nearly all of metamorphic origin have resulted from processes we cannot see in operation and can only imperfectly imitate in experiment. The fourth rule is not a necessary consequence of the facts stated under II and III. It is open to argument whether the processes which originally produced a rock are more deserving of recognition in petrographic system than the processes which have greatly or entirely changed the characters and perhaps even the composition of the original mass, making the rock now accessible to our studies.

As to rule V it can hardly be said to warrant the application made of it, in establishing the three divisions of unstratified, stratified, and dike forms for all kinds of rocks. Where the relations expressed by these terms have some genetic connection with the properties of the rocks they may perhaps be adaptable to classificatory purposes, but there is no logical reason for applying this principle in unqualified form.

The system of Walther seems specially intended to express the changes rocks undergo rather than their characters as now seen, and it is not apparent that the author had in mind the apt and logical analysis of the broad science of rocks which we owe to Naumann.

That the general treatment proposed by Walther for igneous rocks, in naming them volcanic, and making the primary division into unstratified, stratified and dike rocks, has many objections will be sufficiently clear from the preceding discussions of this review. The same is true of the assumption that there exists a satisfactory system for the classification of igneous rocks. The definition of tuffs as composed of magma consolidated in small particles certainly applies to but a small part of the pyroclastic deposits.

## SUMMARY.

The science of petrography, the systematic and descriptive science of rocks, was first fairly outlined by von Leonhard (1823) and Brongniart (1827) through the distinction between the rock and the geological terrane, and the setting up of logical classifications for the former. Neither of these masters gave the science a name.

The systems of von Leonhard and Brongniart necessarily used the condition of ignorance concerning the character of many rocks as a ground for classification. With the increase of knowledge of rocks there have been many attempts to apply new information to systematic purposes. Since both the geological relations and the properties of rocks are highly varied many unlike systems have been proposed during the century, expressing individual opinions as to the relative importance or adaptability of principles for the end in view. Up to the present time, however, no comprehensive classification of rocks has been proposed which even pretends to be natural or logically consistent in all its parts.

When we view past petrographic systems, to judge as to how far they possess natural or artificial features, it is first of all to be noted that the system of Cordier is practically the only one starting from the conception that rock species are natural units and that classification consists in the grouping by more or less artificial means of these fundamental units. Others have sought to make the system of rocks in some degree natural by applying geological factors of occurrence, or genesis, as bases of classification. The view is apparently held by some that in time there will be a comprehensive system expressing all important relations of rocks and that until that result is achieved all arrangements must be regarded as unsatisfactory and temporary.

It appears to the writer that those who hold this attractive and apparently philosophical view may not have in mind the distinction between the formal unit and the rock substance of that unit, or that distinction between the various cross-classifications of petrology and the one system of petrography, with which the nomenclature is specially connected.[1] The belief expressed by Lossen that "geological relations must be recognized as petrographical relations" and the assertion by Rosenbusch that "petrography is an historical science" illustrate this point.

If the system of petrography is to be hierarchical, as the writer believes it should be, the natural element in system is to be provided for in the judicious selection of broad geological factors so related to important characters of rocks that the completed system in the construction of which those characters have been used, will have a logical and appropriate co-ordination and sequence of parts. That this aim has not controlled in the past is evident from the following partial list of designations given to the rocks which are actually consolidation products of magmas; "Composite, crystalline-granular, and porphyritic" (Zirkel); "Non-clastic, composite, massive" (Zirkel); "Composite-simple" (von Lasaulx); Unstratified, Anogene, Massive, Plutonic, Volcanic, Eruptive, Igneous. Here are expressed a number of natural relations, to be recognized in the proper place, but only the last term refers directly to the relation most appropriate for petrographic system. It was not the fact that eruptive force was

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[1] See "The geological versus the petrographical classification of rocks," by WHITMAN CROSS, JOUR. GEOL., Vol. VI, p. 79, 1898.

exerted to bring molten magmas to the sites of the rocks we study, but the fact of the molten condition which gave its stamp of common characters to the products of consolidation.

Arbitrary steps are necessary in the classification of such objects as rocks, exhibiting gradations in all directions. But that fact does not justify such artificial systems as many of those which have been reviewed. Among the most distinctly artificial systems are those of Cordier, Senft, and von Lasaulx; but scarcely less so, as regards igneous rocks, are those which, while using chemical or mineral composition as the basis of arrangement, use only a portion of the mass. For examples: some of the chemical classifications take only certain components into account; Fouqué and Michel-Lévy classify igneous rocks by the character of that variable portion of the magmas consolidating during the second period; Rosenbusch uses the phenocrysts only, in certain parts of his system.

The fundamental requirement that systems should be logical in construction, with consistent and consequent application of principles adopted, has been so commonly disregarded that a summary of instances in point seems unnecessary. Some of the most widely used systems of today are notably illogical as to criteria, as has been pointed out.

One of the most serious defects of modern classifications of igneous rocks is a matter of bad logic, and to this defect the writer wishes to allude once more. It is commonly admitted that the chemical composition of these rocks is their most fundamental characteristic, and many authors would apparently be glad to apply this character in classification. It is generally stated, however, that the chemical is represented by the mineral composition, and as the minerals are so prominent it is convenient to use them in system. But with no further discussion it has been the universal plan to use the minerals in so limited a qualitative way that they do not in fact express chemical composition except in a most crude and inadequate manner. This procedure is purely and simply illogical, if the intention be to represent chemical composition by the minerals of the rock.

That some factors have been introduced into classification in a manner that is quite unscientific seems plain. The age distinction is one of the factors thus abused. It has long been known that no general distinction separated pre-Tertiary and Tertiary igneous rocks. It may be that the average chemical composition of magmas erupted in successive ages has undergone some change; but neither the character of the change, nor, least of all, any special connection with the particular time limit in question, has been established. The assumption that igneous rock textures, such as the granular, porphyritic, or vitreous, are functions of geological form or place of occurrence, is known to be contrary to the facts displayed by the rocks. Both of these assumptions have been and are now used in rock classifications.

Stability of system is certainly desirable, within the bounds of reason. But it is also self-evident that a system of artificial character, in which the subjective element is dominant, can be permanent only by universal consent of petrographers, and such consent is not to be expected. It is a matter of experience that genetic theories have made systems into which they have been introduced very unstable and impossible of general adoption. The danger of using hypotheses in classification has been well characterized by von Cotta, somewhat as follows: Geology is a particularly alluring field for premature attempts at the explanation of imperfectly understood facts; indeed, such attempts are almost unavoidable in the study of this science. When one considers hypotheses simply as such, *i. e.*, as stimulants toward their possible demonstration, then they are not harmful; the danger lies therein that one may believe them already proven and rest contented.[1]

The danger pointed out by von Cotta has been illustrated in the classification of igneous rocks by such able men as von Richthofen, King, and Rosenbusch. As regards the interior of the earth, whence the molten magmas come, we cannot as yet be sure that what we regard as a law today may not be relegated to the status of a theory or even of an hypothesis tomorrow.

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[1] B. VON COTTA, *Gesteinslehre*, 2d ed., 1862, p. vi.

The genetic theory has its proper field of great usefulness in the department of petrology dealing with petrogenesis. Ultimately we may hope and expect that genetic relations of igneous rocks may be available for a more natural classification than is now feasible.

Any system of classification should be broad and thorough enough to include all the objects which it professes to deal with. But the authors of many systems outlined in this review have been obliged to resort to the expedient of *appendices* to bring in rocks not otherwise provided for. Such a necessity is, at once, evidence of the inadequacy of the criteria guiding the authors of such systems.

Even in the class of igneous rocks, propositions for chemical and mineral classifications do not fully recognize the systematic importance of some of the relatively rare constituents. Chemical systems which consider all igneous rocks as mixtures of silicates, or reject magnetite as extraneous, are not comprehensive. Similarly, the schemes which do not provide for the due recognition of titanium minerals, corundum, apatite, sulphides, etc., as important constituents in some cases, are inadequate, even for present uses, and certainly do not provide for future needs which can be clearly foreseen.

In conclusion, the status of systematic petrography at the close of the nineteenth century may be summarized as follows:

1. There is as yet no comprehensive and properly systematic classification of all rocks. All so-called systems exhibit portions in which the rocks are treated in an unsystematic manner, for convenience of description and discussion. The grand divisions are not treated by similarly logical and definite methods.

2. Rocks of igneous origin have been much more thoroughly investigated than others and they have received correspondingly more definite and systematic classification. The factors used in systematic construction pertain to genesis, age, and characters.

*a*. The origin of the great range in chemical composition exhibited by igneous magmas, expressed in theories of magmatic differentiation, is an underlying factor of much importance in the system of Rosenbusch, and is also seen in the desire to recognize consanguinity of the magmas of petrographic provinces, as partially worked out by Iddings and Brögger. The availability of such factors in petrographic system is doubted by many authorities.

*b.* While the distinction of older and younger series of rocks through different sets of names is still found in the German and French systems there is practical unanimity of opinion that the real differences between the rocks are much less fundamental than was supposed. In America, Great Britain, and elsewhere, this distinction is held to be unwarranted.

*c.* The chemical and mineral composition of igneous rocks and their textures are characters used as means of classification in present systems. Chemical composition *per se* is used, but only by considering a portion of some rocks, and hence fails to provide an adequate system. The broad chemical divisions used by some authors are vague and overlapping.

Mineral composition is commonly assumed to represent the fundamental chemical constitution and to be, therefore, a convenient and practicable means of expressing the latter. In practice the qualitative method of applying mineral composition in existing systems destroys its effectiveness as expressing chemical composition.

Structure is variously used in present systems. It is acknowledged to be the product of conditions, and not dependent in marked degree upon mineral development. When applied as a primary factor in classification (as by Rosenbusch) it separates things which are similar in more fundamental characters, and on this ground some authorities believe that structure should be applied in classification after the other characters named.

3. The rocks which have formed upon the surface of the earth by the destruction of older rocks may be viewed from so many standpoints, as regards the origin of materials, agencies of transportation, relations to the earth or to other rocks, characters of materials, and processes of induration, that no consistent arrangement of these objects, deserving the name of a petro-

graphic system, has been proposed. In the existing arrangements the confusion of correlating various cross-classifications into one whole is quite evident.

4. Metamorphic rocks, including all such in which the derived characters are more prominent than the original ones, defy systematic treatment at the present time. Since they have been formed from all kinds of original rocks, by many different processes, and at many sites in the earth's mass, there are many standpoints from which they may be considered, and their classification is a complex problem. Among the facts most difficult to recognize in system are the close resemblance or identity of metamorphic products from originally different rocks, and the similar correspondence between certain secondary and primary rocks. The proposition of Walther to classify all metamorphics with the masses from which they were derived is thus impracticable at the present time, even if it be thought desirable. In relation to this class of rocks systematic petrography is in the condition that its arrangements are tentative, awaiting new knowledge concerning the genesis and essential characters of the objects.

The review of the development of systematic petrography given in the preceding pages has been mainly a discussion of comparatively comprehensive arrangements or systems which have been proposed. It is, of course, true that these systems are but correlations of ideas from many sources, and a complete history of the subject would give to important discoveries of fact and to critical or creative suggestions their due weight in influencing the development of systems. But such influence is difficult to trace, and to have attempted such a history would have involved the expenditure of much more time than the writer could devote to the subject. For this reason a large number of important essays, bearing upon certain features of classification or devoted to discussion of principles, have been left unnoticed because they were not accompanied by general systematic propositions. Among the essays thus disregarded are notable ones by Rosenbusch, Brögger, Becke, Michel-Lévy, Teall, Iddings, Spurr, Turner, and many others.

The telling effect of searching investigations touching controverted points of fundamental significance and of the judicial remarks of those who have carried out such studies is often much greater than either author or reader is aware. In the course of time the influence exerted by a succession of investigations becomes evident in some proposition for the revision of classification. Petrography has thus come to its present condition by a steady natural evolution, and its future growth must undoubtedly follow the same course.

# QUANTITATIVE CLASSIFICATION OF IGNEOUS ROCKS

# CONTENTS.

## PART I. CLASSIFICATION.

## PART II. NOMENCLATURE.

## PART III. METHODS OF CALCULATION.

# SUMMARY.

We present in this work an entirely new system for the classification and nomenclature of igneous rocks, which represents the results obtained after some years of consideration and discussion of the subject in all its bearings.

In uniting our efforts for this purpose we have been actuated by a sense of the seriousness of the responsibility assumed in such an undertaking, and by a conviction that the best results were to be obtained by the co-operation of several workers who agreed on fundamental principles and who were capable of harmonious collaboration.

Originally Professor George H. Williams was associated with us in this work. By his death we have been deprived of a counselor whose judgment we held in the highest esteem, and whose loss we cannot cease to lament.

Many attempts were made to modify in various ways the existing systems of classification in the endeavor to make them answer the demands of modern petrology, and each attempt was successively cast aside on practical trial. It came thus to be perceived by all of us that the main weakness of old systems lay in their fundamental principles and methods and that any new, logical and comprehensive system based on the vast amount of knowledge of igneous rocks acquired in these later years must be built up from the very beginning on different lines from those heretofore employed. After many endeavors in various directions, we gradually evolved the system here presented. Along with its evolution has gone hand in hand the calculation of thousands of analyses by which it has been tested and its formation in large part controlled. It is a *chemico-mineralogical* system based on its own principles, and is in nowise an attempt to reduce any one of existing systems to a chemical basis or to formulate one of them in a chemical way. Its concepts of rocks are in a large measure new, and hence, except in a very small degree, it demands a new nomenclature.

In brief outline, what we propose is as follows: All igneous rocks are classified on a basis of their *chemical composition*; all rocks having like chemical composition are grouped together. The definition of the chemical composition of a rock and of a unit of classification is expressed in terms of *certain minerals* capable of crystallizing from a magma of a given chemical composition, and the expression is *quantitative*. For this purpose the rock-making minerals are divided into two groups, consisting on the one hand mainly of the more highly siliceous alkali- and calci-aluminous ones, and on the other of the ferromagnesian ones. The first group is called mnemonically the *salic* group, the second is the *femic* group. From this category the micas and aluminous augites and amphiboles are excluded for reasons given in full.

For the purpose of completely classifying a rock by this system its chemical composition must be actually known by chemical analysis, or approximately so by physical means or by microscopic, optical methods indicated by the authors. The thousands of rocks of various mineral compositions and textures whose places in this system are indicated by chemical analysis become types for comparison, analogous to type specimens of zoology and botany, by which similar rocks may be approximately classified.

Since it is known that many magmas may crystallize into quite different mineral combinations, according to the influence of attendant conditions upon the union of the various chemical constituents of the magma, it is necessary to select a certain set of salic and femic minerals as uniform standards of comparison. These standard minerals are, for the most part, species commonly formed, but the aluminous pyroxenes, amphiboles, and micas are necessarily excluded. In practice, the molecular composition of a rock, obtained from its chemical analysis, is computed by a regular method into amounts of these standard minerals, and the place of the rock in the system is then easily determined.

The *standard mineral composition* of a rock is called its *norm*, and this may be quite different from its *actual mineral composition*, or *mode*. Methods for obtaining the latter and for indicating its relation to the former are set forth in detail in the Part III, on Calculations.

On the relative proportions of these two groups of standard minerals, the rocks are first divided into five *Classes*, accordingly as one or the other of these two groups alone constitutes the norm, or is *extremely* abundant; whether one or the other is *dominant;* or whether the two are in about *equal* proportions. The *Classes* thus formed are divided into *Orders* on the relative proportions of the minerals forming the predominant group in each case, and in the middle group on the relative proportions of the salic minerals. Thus in the preponderantly salic Classes the Orders are based on the relative amounts of quartz, feldspars, and feldspathoids.

The *Orders* are divided into *Rangs* on the chemical character of the bases in the minerals of the preponderant group in each case; thus, if these were feldspathic, as to whether they are alkalic, alkalicalcic, or calcic. The lowest division or *Grad* obtains only in the three intermediate Classes, and results from the consideration of the relative amounts of the minerals composing the subordinate group.

In addition to these divisions further ones are provided for where necessary by Subclasses, Suborders, Subrangs, and Subgrads.

*Texture* is considered of minor importance in classification, and is taken into account after the chemical and mineral composition.

*Nomenclature.*—The system demands an entirely new nomenclature, and it has been sought to introduce this according to a definite system, the lack of which is so painfully evident in the present nomenclature.

The nomenclature proposed consists of three parts: primarily of substantive names for the magmatic units, implying the chemical composition and the norm, or *standard* mineral composition; secondarily, two sets of adjective terms to be used to qualify the magmatic names; one set referring to the actual mineral composition, or mode, and the other to the texture of the rocks.

The magmatic name consists of a root, derived from a geographical name in all cases except for the names of Classes and Subclasses, and of a suffix. The suffixes are so chosen as to vary in a definite way with the division of the system to which the magmatic name belongs. Thus for Class, Order, Rang, and Grad, the letters *n*, *r*, *s*, and *t* in alphabetical order are used with the vowel *a*, giving in English *ane*, *are*, *ase*, *ate*. For Subclass, Suborder, etc., the vowel is changed to *o*, giving *one*, *ore*, *ose*, *ote*.

The roots forming the names for classes are *sal* and *fem*, mnemonic of the salic and femic minerals constituting their norms, and are combined with prefixes yielding the following: Persalane, Dosalane, Salfemane, Dofemane, and Perfemane.

The roots for the names of the divisions smaller than Class are derived from the names of geographical localities, and as far as possible from those at present in use for rock names, advantage being taken of their connotations as to magmatic character.

The authors propose a nomenclature for field use based on purely megascopic characters.

The work concludes with a discussion of methods of calculating mineral composition from chemical composition and the reverse, and presents tables to aid such calculations.

# PART I.

## CLASSIFICATION.

### INTRODUCTION.

The commonly acknowledged unsatisfactory character of rock classifications in present use, and the unsystematic nomenclature of petrography, have convinced us of the necessity for a complete reconstruction of both. Recognizing the magnitude of this task, yet desiring to see it accomplished as early as possible, we have united our efforts toward the production of a new system of classification and the creation of a nomenclature to express it. Many attempts at improvement of existing schemes of classification have been made in recent years, but they have failed to accomplish important results because they have not gone to the root of the matter.

The discussions of petrographers associated with the International Geological Congress have demonstrated the futility of attempting the regulation of petrographical nomenclature without first fixing the basis of rock classification, since the conceptions by different petrographers of the objects to be named are diverse. And the effort to establish a systematic classification of igneous rocks by international conference and agreement has in like manner proved ineffective because of evident inherent difficulties.

The recently published *Compte Rendu* of the Eighth Session of the International Geological Congress, held in Paris, furnishes an illustration of the diversity of views held by European petrographers, while presenting in definite form the convictions of a considerable number of the foremost workers in this science regarding the principles that should govern the choice of bases of a systematic classification. To a very considerable extent we find ourselves in accord with the opinions expressed in the report of the Russian Committee and in the discussions and report of the Paris Commission of October, 1899. And we are encouraged to hope that the system here presented by us will meet with a cordial reception by those petrographers who, sharing more or less completely our conceptions of the fundamental principles that should control the formation of a systematic classification of igneous rocks, may approve of our method of applying them.

We wish to acknowledge our obligations to all those whose ideas and writings have influenced us consciously or unconsciously; influences which will be evident in many places in the succeeding pages. It is not always possible to credit a particular conception to a particular author. The science of petrography has developed so rapidly, and so many workers have been engaged upon kindred problems, that similar ideas have forced themselves upon investigators. Especially, in our own case, frequent interchanges of thought have so blended and modified our ideas that is difficult for any one of us to identify his own.

In particular we acknowledge our obligations to those masters of petrography from whom we caught inspiration for our petrographical careers. To Professor Ferdinand Zirkel and to Professor Heinrich Rosenbusch, our instructors, whose work and thought have opened the way to a host of students of rocks, we are indebted for much that has influenced us in shaping the system proposed, which is in fact a natural outgrowth of present petrographical conditions.

*Defects of present systems.*—From the review of rock classification in an earlier part of this volume by one of us, it appears that all past and existing classifications of rocks have fundamental weaknesses arising either from the use of theoretical concepts, or from an inconsequent or illogical application of the characters of igneous rocks as bases of their systematic arrangement. That a new nomenclature is required for a new system can scarcely be disputed. The present confusion in petrography is in no small degree due to redefinition of old terms, and to this confusion we have no desire to add. Without going into an extensive discussion of the vitally weak points of existing systems of petrography, upon which all of us have expressed individual opinions, some of the most unsatisfactory features may be briefly stated as follows:

1. There are few definite, clearly enunciated and generally applicable guiding principles, the consequence being that the present systems are to a large extent arbitrary aud subjective, and are capable of being applied differently by different individuals, as is evident from the numerous cases where different names have been given to the same rock, or the same name to obviously different rocks.

2. There is a lack of uniformity in the method of application of existing systems not only among petrographers of different countries, but among those of the same country.

3. The present systems are to a certain extent founded on theory or hypothesis, while classification in order to be stable must eschew all such bases, and be founded only on ascertained facts.

4. Present systems are to a large extent qualitative rather than quantitative, the result being that some given character of rocks is arbitrarily used as a criterion beyond its natural range of application, as, for example, the use of the mere presence of feldspar to distinguish a group of rocks, whether it be the dominant constituent or only a very subordinate one.

5. The construction of modern systems is faulty in that the groups of rocks, or of rock families, now recognized are quite inadequate to express known relationships, and the varying groupings used by different authors are not based upon definite principles, nor are the principles applied uniformly. As a result of this condition, existing systems are highly uneven and it is often necessary to use either too specific or too general terms in naming a given rock.

6. The nomenclature of petrography is quite inadequate to express the relations between the various groups. The single termination makes it impossible to indicate in the name, *per se*, whether it applies to a large or to a small classificatory division, or whether to rocks or minerals, and gives rise to great monotony.

7. As a consequence of these conditions, there is no guide as

to when the use of a new name is necessary or justified, each investigator being his own judge in such matters. In some rock groups which have been recently studied, there is an abundance of new names, while in other more common and longer known groups, a few names are made to do duty for many obviously distinct rocks.

Upon the grounds stated, a new system of petrography seems to us necessary. This conclusion has been reached by us only after many efforts to revise or remodel existing schemes. Our first conferences upon this undertaking were participated in by George Huntington Williams, and our first exchange of suggestions bears the date of May 1, 1893. These efforts on our part, extending over ten years, have brought us from somewhat diverse views to full accord in the system here presented.

## BASIS OF CLASSIFICATION.

The progress in the knowledge of the composition, texture, and occurrence of igneous rocks, as well as in the conceptions of the probable causes of variation among different bodies and within one body of rock, has been such as to justify us in considering the problem of the classification of igneous rocks in the light of certain established facts of a general nature. The recognition of these leads to the establishment of general principles upon which a new system of classification may be based.

*The facts to be considered* may be stated categorically as follows:

The once igneous or molten condition of the magmas from which rocks of this kind have solidified.

The characters of such magmas as solutions.

The physical and chemical properties of such solutions.

The ability of complex solutions to differentiate by osmotic diffusion, liquation, fractional crystallization, or by other processes, under varying conditions of temperature and pressure.

The variations in chemical composition resulting from such differentiation.

The existence of marked chemical variations within igneous masses of small volume in some instances, and of slight variations within bodies of large volume in others.

The absence of fixed proportions of constituents in rocks with two or more mineral components.

The gradations in the chemical and mineral composition of rocks, within limits.

The limited number of the important rock-making minerals.

The existence of rocks having but one mineral component.

The variable crystallization of a chemically homogeneous magma, or of several chemically similar magmas, whereby different combinations of minerals may be produced from chemically similar magmas. In other words, the fact that rocks having diverse mineral compositions may be chemically alike.

The fact that diverse textures develop from the same magma and from chemically similar magmas, and conversely that similar textures develop from chemically different magmas.

The incomplete crystallization of magmas or their solidification into glass in many instances.

The identity of rocks of different geological ages.

The identity of many rocks with different modes of geological occurrence.

*The existence of petrographical provinces* in which the igneous rocks genetically related are distinguishable from those of other regions, when considered in connection with the occurrence elsewhere of similar petrographical provinces and with the gradual transitions between provinces, should be treated as a larger phase of differentiation. Moreover it has been shown by Brögger[1] that similar rocks may be differentiated from different parent magmas in several petrographical provinces, and may occur in two or more unlike series. That is, rocks belonging to distinct provinces may resemble one another so closely in their dominant characters that they would naturally be defined by the same terms. Hence, we conclude that all igneous rocks should

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[1] *Quart. Jour. Geol. Soc.*, Vol. L (1894); p. 36, and *Die Eruptivgesteine des Kristianiagebietes*, Vol. III, p. 57, Christiania, 1898.

be correlated and classified in one comprehensive system based upon principles common to igneous rocks in general.

*The principles* which we consider applicable to the classification of igneous rocks, as criteria by which to judge of the facts to be employed and their method of application, are as follows:

The classification should be free from hypothesis, and be based only on facts or relations determinable in the rock itself.

The classification should be quantitative as far as possible, and each constituent, chemical or mineral, should be given weight in proportion to the amount present in each case, irrespective of its rarity or unusual occurrence.

The chemical composition of the rock is its most fundamental character, being a quality inherent in the magma before its solidification, and is therefore of greatest importance for its correlation with other rocks.

All rocks of like chemical composition should be classed together, and degrees of similarity should be expressed by the relative positions or values of the systematic divisions of the classification.

The mineral and textural characters, being dependent largely on external conditions attending rock solidification, are to be regarded as of subsidiary importance in classification, but should receive due recognition in the system.

Since it is the chemical composition of the magma that is the fundamental character of igneous rocks by which they are to be classified, only fresh, undecomposed, or unaltered rocks are to be employed in establishing such a classification.

A BRIEF DISCUSSION OF VARIOUS PRINCIPLES that have entered into systems of rock classification is introduced at this place in order to make clear our reasons for selecting those employed in creating the system proposed by us.

Rocks have always been recognized as extremely difficult of systematic classification, because of their infinite variation or gradation from one kind to another in many ways. Reviewing the many factors which may be employed in their classification, they are found to fall into two groups, namely, geological relations, and inherent characters; and the task of the systematic petrographer is to select the characters and apply the criteria which will produce the most natural and stable as well as comprehensive and elastic arrangement.

*Of geological relations*, the mode of origin is now universally recognized as the first principle to apply to the sub-kingdom of rocks, to secure the grand divisions of which the igneous rocks are one. The further application of geological mode of origin in subdivision of igneous rocks involves the use of theoretical considerations and produces instability of system.

The relations of geological occurrence have been used in the arrangement of igneous rocks, but unsuccessfully. Geological age cannot now be used without violating the known fact that rocks of many ages are identical in their material qualities.

Some systems of classification now in use are based on supposed relationships between the material characters of igneous rocks and their modes of occurrence as geological bodies, which are only partially in accord with facts, and which therefore introduce serious weakness into the foundation of the systems. There are no particular kinds of rocks that invariably characterize geological bodies of special shapes, such as stocks, laccoliths, dikes, etc. Nor is there any specific texture that indicates the depth beneath the surface of the earth at which a rock has crystallized. While there is unquestionably a relation between the texture and mineral composition developed in a given magma and its physical environment during eruption and intrusion and at the time of its solidification, this relationship is so intricate, and the possibilities of environment so manifold, that it cannot be made a basis for classification.

The effort to classify rocks on a basis of their genetic relationships by grouping them in such a manner as to express the fact that all the rocks of a particular center of eruptive action are the differentiates of some common parent magma introduces the utmost complexity, because each group presents a particular set of relations, and it becomes necessary to recognize almost as many groups as there are known centers of eruption. But as already stated, the members of several groups may resemble one another so closely as to be capable of the same definition and deserving of the same name. The consistent application of such a system of grouping would therefore separate rocks which are alike so far as intrinsic qualities are concerned. And this, according to our conception of classification, is not classification. Many of these facts are essential to the complete petrological understanding and description of rocks, but are not applicable to the construction of a petrographic system.

*The inherent characters* of igneous rocks have always been prominent in the formation of petrographic systems, and are plainly the features it is most natural to select. This was specially pointed out by the fathers of systematic petrography, von Leonard and Brongniart, and has been emphasized in recent discussions. Of these characters chemical and mineral composition, structure or texture, are the most important, the others being comparatively trivial or accidental. Structure or texture is now known to depend so largely on variable conditions attending the consolidation of magmas that it can no longer be given the prominent rôle hitherto assigned to it. Chemical and mineral composition then remain as those characters of igneous rocks most available for their classification. Of these, it is to be noted, that while the two are most intimately related, the former is more fundamental, since it pertains to a magma which may consolidate as a glass or become a holocrystalline rock, and in the latter case the mineral constitution varies with attendant conditions.

### CHEMICO-MINERALOGICAL CLASSIFICATION.

While the chemical composition of igneous rocks is their most fundamental characteristic, it is known that there is an absence of stoichiometric proportions among the chemical elements or components. It is further clear that there is an intricate interrelationship and serial variation among these components and an absence of chemical division lines, or of groups or clusters of similar combinations of elements. These facts show that any subdivision on a purely chemical basis must be arbitrary, unpractical and unsatisfactory.

All holocrystalline, and many of the partially crystalline rocks derive their most obvious characters from the mineral particles composing them. The varying proportions of unlike minerals in rocks are most striking, and other notable features are due to the physical properties of the minerals, their color, cleavage, hardness, etc., or to the relative or absolute size or shape of the particles. It is by reference to these characters that rocks may be most readily described and identified, and it is then desirable that the systematic classification should be constructed as far as may be by the use of mineralogical data in one form or another.

There are, however, reasons why mineral constitution by itself cannot be used in the principal divisions of a comprehensive and logical classification of all igneous rocks. The existence of vitreous rocks forms one of these reasons, because such rocks cannot be classified at all by purely mineralogical criteria. The fact that a given magma may crystallize into different mineral combinations is another reason. Moreover, if mineral composition were a simple function of chemical composition, and if all rocks were holocrystalline, the number of chemically different minerals of importance would make the task of classifying rocks by means of mineral composition alone practically impossible. It, therefore, appears that neither chemical composition nor mineral constitution can be independently applied to the construction of a logical and practical classification of igneous rocks.

The primary minerals in a holocrystalline igneous rock, when considered *chemically* and *quantitatively*, are a full expression of the chemical composition of the magma, and their exact determination furnishes the chemical composition of the rock. To a large extent the mineral composition may be employed as a means of determining the chemical composition, and since the minerals are readily determinable optically in many cases and are a convenient means of identifying rocks, it is advisable *to treat the chemical composition of rocks in terms of minerals*, and to make the basis of primary subdivisions *chemico-mineralogical.*

While this conclusion is, in its general terms, quite commonly asserted as the purpose of existing mineralogical systems of rock classification, it requires but casual consideration to see that a *qualitative* mineralogical system cannot express chemical composition, and a thoroughly *quantitative* scheme has never been formulated.

Before stating the method of classification to be proposed, it is important to point out some of the chemical and mineralogical relationships obtaining in igneous rocks. And first it is to be noted that while the chemical composition of a magma controls in general the kinds of minerals that may crystallize from it, so that quartz forms in the more siliceous rocks, and olivine in those rich in magnesium and iron, still it does not fix absolutely the kinds or the proportions of all of the rock-making minerals. This is due to the fact that a number of these minerals consist of similar elements in diverse proportions, so that two or more different combinations of elements may be developed in chemically similar magmas. Or, as is well known, some of the minerals having a complex composition may be dissociated into less complex ones. A familiar example is the experimental melting of hornblende and the obtaining in its stead pyroxene and magnetite. Another illustration of the same kind of relationship is the chemical identity of some hornblende-andesites and some pyroxene-andesites.

A striking illustration is furnished by the hornblendite and camptonite of Gran, Norway, described by Brögger.[1] The two rocks having almost identical chemical compositions are composed in the first case of somewhat alkalic, aluminous hornblende, and in the second of less aluminous hornblende and feldspar.

The development of biotite in some rocks and its absence from others having like chemical composition is well known; as shown by its presence in some gabbros and its absence from some chemically equivalent basalts; its presence in certain diorites and its absence from equivalent andesites;[2] its develop-

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[1] *Op. cit.*, pp. 60, 93.

[2] IDDINGS, J. P., "The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park," *Twelfth Ann. Rept. U. S. Geol. Surv.* (Washington, 1892), p. 653.

ment in minettes and absence from certain basanites. And with this difference in biotite there is a variation in olivine, hypersthene, magnetite and other minerals within the rocks mentioned.

Other notable illustrations of different mineral development in chemically similar rocks are the madupite of Wyoming[1] and venanzite of Italy,[2] in the latter rock melilite and olivine appearing instead of pyroxene and phlogopite in the madupite; also the nephelite-syenite of Beemerville, N. J.,[3] and the leucite-phonolite of Bracciano.[4] Indeed, instances of the same kind are well known to all, and are constantly increasing in number. It is therefore indisputable that magmas of identical chemical character may and do solidify as very different mineral aggregates, it being also a possibility that they form on solidification no minerals at all, or that they crystallize only in part.

STANDARD MINERAL COMPOSITION.—Whether vitreous or crystalline, all igneous rocks may be correlated by considering what mineral combinations may be developed from their magmas if completely crystallized. But since several mineral combinations are possible for most magmas, it is advisable to select one of these combinations as the standard of comparison. And for uniformity and simplicity it is necessary to select the same one for all rocks having like chemical composition. This may be termed the *standard mineral composition*, which may or may not correspond to the *actual mineral composition.*

Before presenting the reasons for selecting certain minerals as those best adapted for a chemico-mineralogical classification of igneous rocks, let us consider the important rock-making minerals from the general standpoint of their chemical composition. They may be arranged in several groups chiefly

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[1] CROSS, W., "Igneous Rocks of the Leucite Hills, etc." *Am. Jour. Sci.*, Vol. IV (1897), pp. 115–141.

[2] SABATINI, V. I Vulcani di S. Venanzo. Rivista di Min. e Crist., Vol. XXII Padova, 1899, pp. 1–12. *Cf.* ROSENBUSCH. *Sb. Berl. Ak.* (1899) p. 113.

[3] *Bull. 150, U. S. Geol. Surv.* (Washington, 1898), p. 209.

[4] WASHINGTON, H. S., "Italian Petrographical Sketches," JOUR. GEOL., Vol. V (1897), pp. 43, 49.

distinguished by chemical characters, but also by associations in the rocks. They are:

*a*) *Silica and alumina uncombined,* quartz (tridymite) and corundum, together with zircon, which, though commonly present in very small amount, is oftenest found in rocks rich in silica or alumina.

*b*) *Aluminous non-ferromagnesian minerals;* orthoclase, albite, anorthite and mixtures of these, leucite, analcite, nephelite, sodalite, hauynite, noselite, cancrinite, and muscovite.

*c*) *Aluminous ferromagnesian and calcic silicates* (intermediate between *b*) and *d*) ): aluminous pyroxenes and amphiboles, biotite, garnet, tourmaline, melilite, some spinels, etc.

*d*) *Non-aluminous ferromagnesian and calcic silicates:* hypersthene (including enstatite), diopside (including hedenbergite), acmite, olivine (including fayalite and forsterite), and akermanite.

*e*) *Non-siliceous and non-aluminous minerals with titanosilicates;* magnetite, hematite, ilmenite, apatite, titanite, perofskite, and fluorite, together with the native metals, and certain other metallic oxides and sulphides.

If igneous rocks are considered from the standpoint of their mineral composition, they are found to consist of graduating series of quantitatively different mixtures of several groups of minerals, and since they are all necessary to an exact expression of the chemical composition of the rock, each mineral or group of minerals should receive proper recognition according to its quantitative value. Owing to the number of minerals in most rocks, this is a very intricate problem and we have made repeated attempts to solve it by recognizing several independent mineral factors at one time, involving the problem of handling three or more co-ordinate quantities. This was found impracticable as a basis of classification, and it was seen that the most feasible procedure is to recognize such factors successively according to certain degress of qualities or magnitudes possessed by them in comparison with one another. This has been done by grouping them on a basis of chemical identity or resemblance, and of established affinities or associations, and by successively subdividing these groups by subordinate chemical differences or quantitative values. For this purpose it is necessary to assemble all rock-making minerals into two chemically distinguished groups.

These have been made by uniting quartz, corundum and zircon with the aluminous non-ferromagnesian minerals—feldspars, feldspathoids and muscovite—in one group, and by placing the non-aluminous ferromagnesian and calcic minerals—hypersthene, diopside, acmite, olivine, and akermanite—with the non-siliceous and non-aluminous minerals, and titanosilicates,—magnetite. hematite, ilmenite, apatite, etc.—in the other group.

This leaves the aluminous ferromagnesian minerals to be treated in another manner. The reasons for this separation of the minerals, biotite, amphibole and augite, are discussed at length in a later part of this article, but it may be said here that their variable composition and occurrence, together with the fact that they may be considered as mixtures of aluminous and non-aluminous molecules, make it advisable to defer their introduction into the system of classification until the actual mode of crystallization of the rocks is taken into account. Since it is possible that a magma of any given chemical composition may crystallize without the development of these minerals, and since the chemico-mineralogical expression of igneous magmas is greatly simplified by not considering these minerals until the particular crystallization of the magma is to be expressed, we are justified in omitting them from the two groups of minerals which are to be employed in determining the standard mineral composition of an igneous rock. These two groups of *standard minerals* are:

GROUP I: SALIC MINERALS.

| | | |
|---|---|---|
| Quartz, $SiO_2$ | | Q |
| Zircon, $ZrO_2.SiO_2$ | | Z |
| Corundum, $Al_2O_3$ | | C |
| Orthoclase, $K_2O.Al_2O_3.6SiO_2$ | or | F |
| Albite, $Na_2O.Al_2O_3.6SiO_2$ | ab | |
| Anorthite, $CaO.Al_2O_3.2SiO_2$ | an | |

| | | | |
|---|---|---|---|
| Leucite, $K_2O.Al_2O_3.4SiO_2$ | lc | L | |
| Nephelite $Na_2O.Al_2O_3.2SiO_2$ | ne | | |
| Kaliophilite, $K_2O.Al_2O_4.2SiO_2$ | kp | | |
| Sodalite, $3(Na_2O.Al_2O_3.2SiO_2).2NaCl$ | so | | |
| Noselite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$ | no | | |

GROUP II: FEMIC MINERALS.

| | | | |
|---|---|---|---|
| Acmite, $Na_2O.Fe_2O_3.4SiO_2$ | ac | P | |
| Sodium metasilicate, $Na_2O.SiO_2$ | ns | | |
| Potassium metasilicate; $K_2O.SiO_2$ | ks | | |
| Diopside, $CaO.(Mg, Fe)O.2SiO_2$ | di | | |
| Wollastonite, $CaO.SiO_2$ | wo | | |
| Hypersthene, $(Mg, Fe)O.SiO_2$ | hy | | |
| Olivine, $2(Mg, Fe)O.SiO_2$ | ol | O | |
| Akermanite, $4CaO.3SiO_2$ | am | | |
| Magnetite, $FeO.Fe_2O_3$ | mt | H | M |
| Chromite, $FeO.Cr_2O_3$ | cm | | |
| Hematite, $Fe_2O_3$ | hm | | |
| Ilmenite, $FeO.TiO_2$ | il | T | |
| Titanite, $CaO.TiO_2.SiO_2$ | tn | | |
| Perofskite, $CaO.TiO_2$ | pf | | |
| Rutile, $TiO_2$ | ru | | |
| Apatite, $3(3CaO.P_2O_6).CaF_2$ | ap | A | |
| Fluorite, $CaF_2$ | fr | | |
| Calcite, $CaO.CO_2$ | cc | | |
| Pyrite, $FeS_2$ | pr | | |
| Native metals and other metallic oxides and sulphides. | | | |

*Sal, Fem, and Alfer.*—For convenience in subsequent discussion, we will anticipate the question of nomenclature, and introduce here three terms which will be frequently used. To express concisely the two groups of standard minerals and their chemical characters in part, the words *sal* and *fem* have been adopted. The former is employed to designate Group I, mnemonically recalling the *s*iliceous and *al*uminous character of its minerals. *Fem* indicates Group II, since its minerals are dominantly *fe*rro*m*agnesian. As adjectives to express these ideas the words *salic* and *femic* will be used. In certain formulæ employed later the words *sal* and *fem* will be used in the sense just explained, as indicating any one or all of the minerals of the respective groups. Subsequently other mnemonic syllables will be similarly treated.

The intermediate group *c*) of aluminous ferromagnesian and calcic silicates will be designated *alfer* or *alferric* group, this name recalling the fact that these minerals are characterized by the presence of *al*umina and *fer*ric oxide.

*Group I.*—The minerals of groups *a*) and *b*) have been united to form the salic group (I) because of the well-recognized relations between the development of quartz, feldspar and feldspathoids in rocks and the available silica in the magmas; these minerals forming frequent series of rocks with a regular range of silica. It is also done because of the association of notable amounts of zircon and corundum with these minerals in the more quartzose and feldspathic rocks. And further it is in accord with the stronger affinities of the bases, potassium and sodium, for silica and alumina, which will be discussed later.

The kaliophilite molecule is recognized, since its presence is necessary in a few magmas so low in $SiO_2$ as not to allow the formation of both leucite and akermanite. Muscovite is omitted from the list in order to simplify the process of calculation. It may be considered as made up of orthoclase with corundum and water. Analcite is also omitted for a similar reason. It may be considered to be composed of albite, nephelite and water. Hauynite is omitted because it may be regarded as calcic noselite, and because it introduces needless complications into the calculation. The standard $SO_3$-bearing feldspathoid is therefore considered to be a purely sodic noselite. Cancrinite is likewise omitted as being in most cases of secondary origin, as well as for purposes of simplification.

*Group II.*—The minerals of groups *d*) and *e*) have been united to form the femic group (II) because of their freedom from alumina and their association in notable amounts in rocks low in silica and alumina. They are in this sense antithetical to the salic minerals.

Wollastonite ($CaSiO_3$) is added to the list of femic minerals in order to simplify the calculation of standard minerals in rocks rich in calcium, which may actually enter aluminous molecules, such as garnet.

The simple metasilicate molecule $Na_2O \cdot SiO_2$, analogous to that of wollastonite, is assumed to be present in rocks in which there is an excess of alkalies over $Al_2O_3$ and $Fe_2O_3$. It appears in the arfvedsonite molecule, which develops in such rocks. But this mineral, being alferric, is not included among the standard minerals for reasons already given.

In like manner the simplified *akermanite* molecule, $4CaO.3SiO_2$, is included among the standard minerals in place of melilite, because of the alferric character of the actual melilite, our uncertain knowledge of its real composition, and its complexity. The $Na_2O$ and $Al_2O_3$ with $2SiO_2$ of melilite are calculated as entering into a nephelite molecule, the $Fe_2O_3$ is referred to magnetite or hematite, leaving the CaO, partly replaced by MgO, and the remaining $SiO_2$ in approximately the akermanite ratio of 4 : 3. The introduction of this molecule into the calculation is necessary in rocks so low in $SiO_2$ that a subsilicate must develop.

The molecule $(Mg, Fe)O.Fe_2O_3.SiO_2$, which is characteristic of augite, has been omitted for the reason that the ferric oxide is largely replaced by alumina, and because its introduction complicates the problem of calculation.

*Method of calculation.*—In order to determine the kinds and amounts of standard minerals that may express the composition of a given rock, to establish its place in the system, we may proceed by a consideration of its chemical composition as given by chemical analysis, or by a consideration of its actual mineral composition as determined by optical investigation, or we may compare it with known rocks whose compositions have been previously determined.

And since it is advisable to select the same mineral combination for the basis of comparison of chemically similar rocks, as already stated, and since there are gradual transitions among igneous rocks, it is necessary to follow the same method of procedure in calculating the kinds and amounts of the standard minerals for all rocks. The method adopted by us is explained in detail in a later part of this paper. It is based upon certain well-known chemico-mineralogical relations affecting the salic and femic minerals, both as regards the proportions of their chemical constituents, the relative affinities of the bases for silica, and the frequent associations of certain of the rock-making minerals.

The method has been developed by considering, first, the chemical composition of igneous rocks, and by devising a plan for the calculation of standard minerals from it. Then, the *actual* mineral composition of holocrystalline rocks has been taken into account, and a plan devised, after reckoning the proportions of these minerals, for estimating their approximate chemical composition and from these data calculating the *standard* mineral composition of the rock.

It is evident that rocks that are not holocrystalline, or those in which the proportions of the actual minerals cannot be determined, must be classified in the first instance by means of chemical analysis. Subsequently similar rocks may be classified with greater or less precision by comparison with rocks having similar textures and the same actual mineral compositions, which have been analyzed chemically.

In comparing the relative quantities of different minerals in rocks, either their mass or their volume may be made the basis of comparison. In calculating the mineral composition from the chemical composition of the rock, the mass is the natural unit of comparison. The same is true if mechanical separation of the mineral constituents is undertaken. When a comparison is made by the eye, megascopically or microscopically, the basis of comparison is volume. This may be transformed into mass by multiplying the volume by the specific gravity of the mineral. The optical methods of estimation being less exact than those first mentioned, the basis of comparison should be mass.

## CONSTRUCTION OF THE SYSTEM.

It is proposed to arrange igneous rocks by a system which shall express their quantitative chemical and mineral constitutions. With the known range and degree of variation in these characters it is plain that any system of classification must be arbitrary.

As has been pointed out, the efforts to express the quantitative variation in rocks by means of several variables have shown that such a method is undesirably complicated. And we have sought to find a way for making groups of different taxonomic value by subdivision in a dichotomous manner based on the comparison of successive pairs of factors, since the simplest mode of construction is best.

The mineral constituents of igneous rocks may exist in all proportions from 0 to 100 per cent. whether considered as part of the whole rock, or as part of the group of standard minerals to which they may belong. For example one rock may consist entirely of feldspar, while another has none. And there are intermediate rocks containing all possible percentages of feldspar between these extremes. There are equally wide ranges for some of the chemical constituents, considered either with reference to rocks or to mineral groups. Thus the feldspars of one rock may be wholly alkalic, those of another wholly calcic, and between these extremes there are all possible gradations. Among alkalic feldspars are those purely potassic, others wholly sodic, besides all possible intermediate mixtures of these.

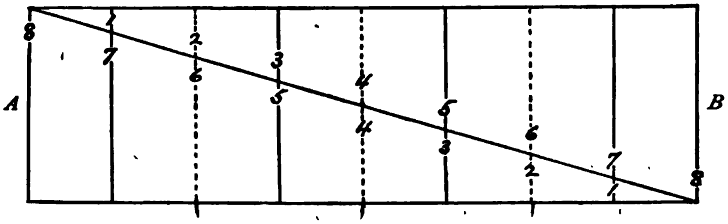
On account of the absence of natural division lines in such series of two variable factors, it is necessary to establish arbitrary divisions. We have accomplished this by considering certain simple proportions as *center-points*, about which variations may be allowed within limits, which limits become the boundaries between petrographical units.

The simplest proportions are: first, those two in which one factor constitutes the whole, and the other factor is absent; second, that in which both factors are present in equal amounts.

Other center-points should be selected with equal respect to these, and may be placed either midway between the three just mentioned, or at shorter intervals. It has appeared to us best to select those midway between the first three, namely, at points representing the proportions three to one, and one to three, making in all five divisions.

It will be noted that the rocks, or mineral or chemical groups, corresponding to the center-points of these divisions seem to have a special value as classificatory types, but we wish to point out that this is not actually the case. Such rocks or such groups, are not more important, considered quantitatively, than those occurring in any other part of the system, even on the boundary between neighboring divisions.

This fivefold method of subdivision may be expressed graphically as follows:



These divisions or units may be described as:

I. One in which the center-point is where the first group is present alone, 8 : 0.

II. One in which the center-point is where the first group is three times the second, 6 : 2.

III. One in which the center-point is where both groups are present in equal amounts, 4 : 4.

IV. One in which the center-point is where the second group is three times the first, 2 : 6.

V. One in which the center-point is where the second group alone is present, 0 : 8.

The dividing lines between these center-points will occur at the following ratios: 7 : 1, 5 : 3, 3 : 5, and 1 : 7. The ranges of the five divisions are given by the expressions:

$$\text{(I)}\,\frac{A}{B} > \frac{7}{1}, \quad \text{(II)}\,\frac{A}{B} < \frac{7}{1} > \frac{5}{3}, \quad \text{(III)}\,\frac{A}{B} < \frac{5}{3} > \frac{3}{5},$$

$$\text{(IV)}\,\frac{A}{B} < \frac{3}{5} > \frac{1}{7}, \quad \text{(V)}\,\frac{A}{B} < \frac{1}{7}.$$

The divisions may be defined in general terms as:

I. In which $A$ is alone present or is *extremely* abundant.
II. In which $A$ *dominates* over B.
III. In which both $A$ and B are present in *equal* or *nearly equal* amounts.
IV. In which B *dominates* over $A$.
V. In which B is alone present or is *extremely* abundant.

The factor which is extreme or dominant over the other, will be spoken of as *preponderant*, the other being *subordinate*.

To indicate whether one of a pair of factors is present in greater or less amount than one-eighth of the combined pair of factors, that is, $\frac{A}{B} \gtrless \frac{1}{7}$, we have adopted the terms *notable* and *negligible*. The former means that it is present in greater amount, and the latter that it is present in less amount, than that proportion.

It is to be noted that the smallest amount of any factor which we recognize as *notable* in a particular division of the system is one-eighth of the combined pair of factors, not necessarily one-eighth of the whole rock, since the pair of factors may be a fraction of the entire rock.

This fivefold method of subdivision will be further applied to that factor of a pair which is *extreme* or *dominant* over the other, or, in the case where both are present in equal amounts, it will be applied first to that one which is deemed to be of the greater importance, and subsequently, when necessary, to the less important factor.

In the case of one factor which is subordinate to another, but not negligible, $\left(< \frac{3}{5} > \frac{1}{7}\right)$, such a manifold subdivision is not advisable, since one-fourth of the factor in question would be less than one-eighth of the pair, and hence negligible. In this case we have adopted a threefold division, by retaining the central division of equal proportions $\left(< \frac{5}{3} > \frac{3}{5}\right)$, and uniting the dominant and extreme divisions. In these divisions there is one where two factors are equal or nearly equal $\left(< \frac{5}{3} > \frac{3}{5}\right)$, and two where one factor dominates or is extreme $\left(> \frac{5}{3}\right)$. Strictly, the subdivision here should be into thirds, but, in view of the confusion liable to arise from the change in proportions the method adopted seems the most advisable one.

No subdivision need be made of a factor which is present in negligible amount, the other factor being extreme, since the whole subordinate factor falls within the allowable limit of variation.

It may be noted in this place that certain prefixes are used in connection with mineralogical and chemical terms to indicate that a factor is *extremely* abundant, or is *dominant.* In the first case the prefix is *per.* In the second case it is *do* or *dom.* When comparison is made on a threefold basis, and one factor *predominates* over another $\left(> \frac{5}{3}\right)$, the prefix is *pre.*

Since this classification is largely a chemical one, and since in all the calculations of minerals the molecular amounts of each constituent only are used, it must be borne in mind that all chemical comparison is made on the basis of the relative number of molecules, that is, it is purely molecular. For this purpose all percentages in analyses must be reduced to molecular ratios, by dividing each percentage by the proper molecular weight.

### OUTLINE OF THE SYSTEM.

The subdivisions of igneous rocks proposed by us, based upon the principles discussed in the preceding pages are as follows:

CLASS, SUBCLASS.
ORDER, SUBORDER.
RANG, SUBRANG.
GRAD, SUBGRAD.

The word *Rang*, which is an obsolete form, equivalent to *Rank*, has been chosen instead of *Rank* to avoid confusion, since it is desirable that the technical term should differ from one which is in common use for other purposes. The same is true of *Grad* which is an old form of *Grade.*

The four terms — *Class*, *Order*, *Rank* and *Grade* — were at first selected because they are of the same category, the first two being commonly used in classification. But Rank and Grade are so frequently employed in a general sense that it is advisable to substitute archaic forms in their stead.

These divisions, which are successively smaller, are based on characters of the magma of less and less importance. In other words, the highest divisions express the broadest and quantitatively most important magmatic characters, those next to them less important ones, and so on. It has been our aim to select the sequence of characters in accordance with this plan, and also to have homologous divisions throughout the system based on the same kinds of characters.

The broadest distinguishing chemical characteristics are expressed by the aluminous non-ferromagnesian minerals and their associates, quartz and zircon, the *salic* minerals, on the one hand; and by the ferromagnesian non-aluminous minerals and their associates, titanite, apatite, etc., the *femic* minerals, on the other.

Consideration of the salic and femic mineral groups shows, however, that the former is more simple in composition than the latter, so that certain modifications, not of the principles, but of their application, will be necessary in places.

Thus the salic minerals are composed chiefly of $SiO_2$ as representing the acid radical, with small amounts of Cl and $SO_3$ in the sodalite group, and of $K_2O$, $Na_2O$ and CaO as representing the bases, these last being always accompanied by an equal amount of $Al_2O_3$, except in the sodalite group, where this is slightly less than the soda. The alumina, in most cases, reckoned among the bases, may play the rôle of acid to some extent in certain cases. On the other hand in the femic minerals, leaving apatite, fluorite, sulphides, etc., out of account, $SiO_2$, $Fe_2O_3$ and $TiO_2$ represent the acid radicals (the last two possibly uncombined with a base as hematite and rutile), and $K_2O$, $Na_2O$, CaO, MgO and FeO represent the bases.

Consequently, to keep to our system of two factors, already described, a more numerous subdivision of the divisions in which the femic minerals preponderate is necessary. But, as will be seen, this can readily be done without transgressing the general principles on which the system is based or affecting the homologous characters of the various divisions in different parts of the scheme.

The principles on which the divisions enumerated above are made may be stated as follows:

*Class.*—This, the broadest division, expresses the most general chemico-mineralogical character of the magma, and is therefore based on the relative proportions of the salic and femic mineral groups as calculated in the standard mineral composition of each magma. In Classes all the salic minerals calculated for a magma are contrasted with all the femic minerals.

*Subclass.*—This division is based on certain broad chemical distinctions in the salic and femic groups, which make it possible to divide each of them into two parts. These will be explained in detail when these divisions are described at length later.

Classes and Subclasses exhibit the broadest and most general characters of the magma, and are based only on the salic and femic mineral groups, and the parts into which these may be most broadly divided on certain chemical lines. More special chemical characters of the salic and femic minerals in each class are next to be distinguished, and since both cannot be indicated at once, according to our principle of dealing with only two factors at a time, we consider first one group of characters and then the other. In accordance with the principle of giving importance to constituents on the basis of their relative proportions, the characters of the preponderant group, salic or femic, will be considered first until they are fully described, and then those of the subordinate group, femic or salic, will be taken up. The divisions from Order to Subrang are based on the chemical characters of the preponderant standard mineral group, while the divisions from Grad to Subgrad will be based on the chemical characters of the subordinate mineral group.

*Order.*—The salic minerals being in the great majority of cases silicates and quartz, and the silica being the most abundant component of these silicates, it is quantitatively the most important chemical character of the salic minerals. Moreover the femic minerals in most rocks are silicates, and in them also silica is quantitatively the largest factor. Less abundant femic minerals are ferrates, titanates, and silicotitanates, besides still less frequent minerals of other kinds.

For these reasons the chemical characters of the salic and femic minerals of first importance quantitatively are the acid components, $SiO_2$, $TiO_2$, $Fe_2O_3$, which might be expressed uncombined with bases, or by mineral molecules. In order to express as far as possible the mineral composition together with the chemical it is advisable to express the relative amounts of these acids by means of mineral subgroups.

Orders in Classes with preponderant salic minerals are consequently based on the proportions of quartz to the feldspars, and of feldspars to feldspathoids, since these proportions correspond to differences of $SiO_2$ in the salic minerals. In Classes with preponderant femic minerals Orders are based on the proportions between silicate and non-silicate minerals in the first instance, and the recognition of the other acid components occurs in subdivisions of Orders.

*Suborder.*—In those Orders in which there are preponderant amounts of acid components other than silica, the most frequent of these being $Fe_2O_3$ and $TiO_2$, we may distinguish the relative proportions of these in Suborders. They occur in those parts of the system where minerals of the M subgroup preponderate.

*Rang.*— Having thus recognized the acid components, with the exception of the radicals Cl and $SO_3$, which can only be present to a subordinate extent, we have now to take up the recognition and expression of the bases in the magma. Consequently, Rangs are formed on the chemical characters of the bases in the minerals of the preponderant salic or femic group, according to the Class under consideration. And since there are several of these bases generally present it is necessary to treat them in successive groups. The first and most general division constitutes Rangs.

*Subrang.*—The comparison of those bases which are united to form the groups of bases recognized in forming Rangs constitutes Subrangs.

*Grad.*—The characters of the subordinate mineral group, femic or salic, will be treated in a manner analogous to that employed when considering the preponderant, salic or femic, group, the only difference being that as the group under consideration is subordinate fewer distinctions will be needed.

Grads will be based on the general acidic proportions in the minerals of the subordinate group, and will follow the plan of the divisions for Order in the preponderant group.

*Subgrad.*—These divisions will follow the lines of the subdivisions for Rang and Subrang, and will express the general and special chemical characters of the bases of the minerals of the subordinate mineral group.

*Sections.*—The application of the above principles shows, however, that in certain points more numerous subdivisions are needed. This necessity is met by the formation of *Sections* of any of the divisions above described. These Sections will be based on more special characters according to circumstances. No general rule can be laid down for them, but they will be explained in their respective places in the subsequent description of the various divisions.

*Family and Series.*—The grouping of rocks proposed in this system of classification is for the purpose of bringing together rocks that are alike chemically, and also mineralogically and texturally. There is need, however, in the broader treatment of igneous rocks, especially with reference to their genetic relations and to their occurrence in petrographic provinces, to group them in other ways. For these purposes the terms *Family* and *Series* are appropriate, and it is proposed that they be used as follows:

The term *Family* may be applied to a group of rocks that have been developed genetically from a common magma by processes of differentiation. In its broadest sense it may be applied to all the rocks of a petrographic province. But it is evident that there may be genetic groups of several degrees of consanguinity, for which more specific designations will be necessary. It is suggested that for these groups terms analogous to Family be used.

The term *Series* may be used, in an extension of Brögger's sense,[1] for groups of rocks characterized by similar ratios of certain constituents, as alkalies, but with varying amounts of other constituents, as silica. These series will be of very different characters dependent on the petrographic province, and will have no place in the system proper, since they will traverse it in all directions. They may be designated, as at present, by the use of the names of the extremes, with or without that of an intermediate member.

CLASSES.—It is proposed to divide igneous rocks into five Classes, according to the calculated proportions of the standard mineral groups above defined. As previously stated, these groups are designated as *sal* and *fem* in formulæ, and the descriptive adjectives derived from these are given below.

$$\textit{Class I:}\quad \frac{\text{sal}}{\text{fem}} > \frac{7}{1}\text{, persalic.}$$

This Class contains rocks *extremely* rich in the salic minerals —quartz, feldspars, feldspathoids, and corundum.

$$\textit{Class II:}\quad \frac{\text{sal}}{\text{fem}} < \frac{7}{1} > \frac{5}{3}\text{, dosalic.}$$

In the rocks of this Class the salic minerals are ***dominant*** and the femic minerals ***subordinate***.

$$\textit{Class III:}\quad \frac{\text{sal}}{\text{fem}} < \frac{5}{3} > \frac{3}{5}\text{, salfemic.}$$

In this Class fall the rocks in which the salic and femic minerals are ***equal or nearly equal*** in amount.

$$\textit{Class IV:}\quad \frac{\text{sal}}{\text{fem}} < \frac{3}{5} > \frac{1}{7}\text{, dofemic.}$$

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[1] *Die Eruptivgesteine des Kristianiagebietes*, Vol. I (1894), p. 169.

The femic minerals are here ***dominant*** and those of the salic group ***subordinate***.

*Class V:* $\frac{\text{sal}}{\text{fem}} < \frac{1}{7}$, perfemic.

The rocks of this Class are extremely rich in the femic minerals—pyroxenes, olivine, magnetite, etc.

SUBCLASSES.—The next step in the systematic subdivision takes account of the distinctions among the standard minerals constituting the salic and femic groups. There being a considerable number of these minerals in each group, it is necessary for reasons already given to divide each group into two parts. Of the salic minerals, quartz, feldspar and the feldspathoids form a closely associated series when considered petrographically and chemically, and may be contrasted with corundum, zircon or other salic minerals. Group I, therefore, falls into Part 1, quartz, feldspars and feldspathoids, indicated in certain abbreviated expressions by the letters Q, F and L, and into Part 2, corundum, zircon, etc., indicated respectively by C and Z.

Group I.
- Part 1. *Quartz* (Q), *Feldspars* (orthoclase, albite and anorthite) (F). *Feldspathoids* (leucite, nephelite, sodalite, noselite) (L).
- Part 2. *Corundum* (C) and *Zircon* (Z).

Similarly, of the femic minerals, the pyroxenes, olivine, akermanite, magnetite, ilmenite and titanite are closely associated in rocks, and form frequent transitional series of rocks with different proportions of these minerals. They may be grouped together as Part 1 of Group II, and contrasted with apatite, fluorite, pyrite, the metals and other femic minerals constituting Part 2. In abbreviated expressions minerals of Part 1 are indicated by the letters P, O and M, those of Part 2 collectively by A.

Group II.
- Part 1. *Pyroxenes* (diopside, hypersthene, wollastonite and acmite) (P). *Olivine* and *akermanite* (O). *Magnetite*, *hematite*, *ilmenite*, *rutile*, *perofskite* and *titanite* (M).
- Part 2. *Apatite*, *fluorite*, *pyrite*, etc. (A).

Subclasses in Classes I, II and III are made on a fivefold basis by considering the relative proportions of the two parts of the salic group, just described. The reasons for using the salic minerals in Class III, instead of the femic, are given in the discussion of Orders. In Classes IV and V Subclasses are formed on the proportions of the two parts of the femic group.

In Classes I, II and III the divisions will be as follows:

Subclass 1: $\frac{QFL}{CZ} > \frac{7}{1}$.

Subclass 2: $\frac{QFL}{CZ} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{QFL}{CZ} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{QFL}{CZ} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{QFL}{CZ} < \frac{1}{7}$.

In Classes IV and V the divisions will be:

Subclass 1: $\frac{POM}{A} > \frac{7}{1}$.

Subclass 2: $\frac{POM}{A} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{POM}{A} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{POM}{A} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{POM}{A} < \frac{1}{7}$.

In the first three classes the distinctions between corundum and zircon may be made in those subclasses in which they are present in notable amount, by the formation of *Sections* as follows:

Section 1: $\frac{C}{Z} > \frac{7}{1}$.

Section 2: $\frac{C}{Z} < \frac{7}{1} > \frac{5}{3}$.

Section 3: $\frac{C}{Z} < \frac{5}{3} > \frac{3}{5}$.

Section 4: $\frac{C}{Z} < \frac{3}{5} > \frac{1}{7}$.

Section 5: $\frac{C}{Z} < \frac{1}{7}$.

In Classes IV and V, Sections may be made analogously, when it is necessary to recognize distinctions between notable amounts of apatite and various metals and sulphides. They need not be given here as the principles controlling them are the same as above.

It will be noted that the vast majority of igneous rocks of all Classes belong to the first Subclass in each Class. There are few rocks known belonging to most of the Subclasses here proposed, but if ever found their classification is thus provided for and will not disturb that of the rocks already known.

In the remainder of this article the classification set forth pertains to Subclasses I of each of the five Classes, unless otherwise stated.

ORDERS.—The division of Subclasses to form *Orders* is made on a basis of the relative proportions of the standard minerals in the preponderant group.

*For Classes I and II* the preponderant minerals are salic; and in Class III salic minerals are considered before femic, and since minerals of Part 1 are preponderant over those of Part 2 the former are made the basis of subdivision, which is as follows:

*a*) Quartz, Q.
*b*) Feldspars (orthoclase, albite, anorthite), F.
*c*) Feldspathoids (lenads) (leucite, nephelite, sodalite and noselite), L.

Owing to the fact, already discussed, that quartz and the feldspathoids (lenads) are in almost all cases antithetical, so that they do not occur together, these three factors may be employed serially and in the first three Subclasses of Classes I, II and

III the Orders are formed by a double application of the plan of fivefold division, resulting in nine Orders.

Owing to the cumbersomeness of the phrases necessary to describe Orders when the mineralogical group-names are employed quantitatively, it is advisable to use abbreviated terms mnemonic of these mineralogical groups. For these we suggest the following syllables: *quar*, mnemonic of quartz; *fel*, mnemonic of feldspar; *len*, mnemonic of leucite and nephelite, which is understood to include the other standard feldspathoids, sodalite and noselite. From these syllables, with the addition of the proper quantitative prefixes already mentioned, are formed adjectives descriptive of the several Orders as given below.

On account of the resemblance between the words feldspar and feldspathoid, in such frequent use, we suggest for the latter the term *lenad*.

| | | | |
|---|---|---|---|
| Order 1: | $\frac{Q}{F} > \frac{7}{1}$, | quartz extreme, | perquaric. |
| Order 2: | $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$, | quartz dominant, | doquaric. |
| Order 3: | $\frac{Q}{F} < \frac{5}{3} > \frac{3}{3}$, | quartz and feldspar equal, | quarfelic. |
| Order 4: | $\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$, | feldspar dominant over quartz, | quardofelic |
| Order 5: | $\frac{Q \text{ or } L}{F} < \frac{1}{7}$, | feldspar extreme, | perfelic. |
| Order 6: | $\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$, | feldspar dominant over lenad, | lendofelic. |
| Order 7: | $\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$, | feldspar and lenad equal, | lenfelic. |
| Order 8: | $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$, | lenad dominant, | dolenic. |
| Order 9: | $\frac{L}{F} > \frac{7}{1}$, | lenad extreme, | perlenic. |

It will be noted that in Class III, in which the salic and femic minerals are present in equal or nearly equal proportions, *Orders* are established as though the salic minerals were preponderant. This has been done for the reason that both groups of minerals being present in nearly equal amounts, it is necessary to select one group arbitrarily for the basis of division to form *Orders*. Preference is given to the salic group because the greater number of rocks belonging to this class, so far as known, contain slightly more salic minerals than femic, within the range of $\frac{5}{3}$ and $\frac{3}{5}$, Moreover, the present custom of classifying these rocks primarily on a basis of the feldspathic constituents may be allowed to influence the choice. The division of Class III to form *Orders* is therefore the same as those in Classes I and II.

*For Classes IV and V* the dominant minerals are femic, and the division to form Orders must be based on the relative proportions of minerals of the first Part of this group. They may be grouped into silicates, 1, and non-silicates with titanosilicates, 2. The silicates are further divided into *a*) metasilicates, and *b*) lower silicates, as follows:

1 { *a*) Pyroxenes, diopside, wollastonite, hypersthene, and acmite, P.
  *b*) Olivine and akermanite, O.
2 Magnetite, hematite, ilmenite, titanite, etc., M.

Orders in these Classes are formed by comparing subgroups 1 and 2, the silicates and non-silicates. For adjectives to describe these Orders we suggest the following syllables mnemonic of the subgroups of femic minerals: *pol*, to indicate pyroxene and olivine with akermanite; *mit*, to indicate magnetite, ilmanite, titantite and the other minerals of this subgroup. For adjectives to describe Sections of Orders, based on a comparison of the two parts of the silicate subgroup we suggest the syllables: *pyr*, denoting the pyroxenes, and *ol*, denoting olivine and akermanite.

| | | | |
|---|---|---|---|
| Order 1: | $\frac{P+O}{M} > \frac{7}{1}$, | femic silicate extreme, | perpolic. |
| Order 2: | $\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$, | femic silicate dominant, | dopolic. |
| Order 3: | $\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$, | femic silicate and non-silicate equal, | polmitic. |

Order 4: $\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$, femic non-silicate dominant. domitic.

Order 5: $\frac{P+O}{M} < \frac{1}{7}$, femic non-silicate extreme. permitic.

*Sections of Orders.*—The division of Orders into Sections is needed in Classes IV and V, to express the relative proportions of the subgroups of the preponderant mineral groups, that is, the proportions between the pyroxene and olivine subgroups.

In Orders 1, 2, and 3 of Classes IV and V, where the polic minerals are extreme, or dominate over, or are equal to the mitic, this division is carried out on a fivefold basis and results as follows:

Section 1: $\frac{P}{O} > \frac{7}{1}$, pyroxene extreme. perpyric.

Section 2: $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$, pyroxene dominant. dopyric.

Section 3: $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$, pyroxene and olivine equal. pyrolic.

Section 4: $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$, olivine dominant. domolic.

Section 5: $\frac{P}{O} < \frac{1}{7}$, olivine extreme. perolic.

SUBORDERS.—In Orders 4 and 5 of Classes IV and V the non-silicate, mitic, minerals preponderate. The subgroups of these minerals, in greatest abundance and most characteristic of rocks belonging to these Orders, contain $Fe_2O_3$ and $TiO_2$. The first subgroup includes magnetite and hematite, and is indicated by the symbol H. The second subgroup includes ilmenite, titanite, perofskite and rutile, and is indicated by T. For these subgroups we suggest the syllables *hem* and *til*, mnemonic of the minerals composing then. The relative proportions of these minerals are recognized in Suborders on a fivefold basis, as follows:

Suborder 1: $\frac{H}{T} > \frac{7}{1}$, perhemic.

Suborder 2: $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$, dohemic.

Suborder 3: $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$, tilhemic.

Suborder 4: $\frac{H}{T} < \frac{3}{5} > \frac{1}{7}$, dotilic.

Suborder 5: $\frac{H}{T} < \frac{1}{7}$, pertilic.

Rang.—The division for *Rang* is based on the general chemical character of the bases in the minerals of the preponderant group in each *Class*, that is, in the salic or femic minerals used for the formation of *Orders*.

For salic minerals this is expressed by the terms *alkalic* and *calcic*, which relate to the feldspars and lenads. Divisions are based on the proportions of molecules of $K_2O' +$ $Na_2O'$, to $CaO'$ in these minerals, $K_2O'$, $Na_2O'$ and $CaO'$ being the parts of these rock components allotted to salic minerals. The divisions in Classes I, II and III are fivefold:

Rang 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{7}{1}$, peralkalic.

Rang 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{7}{1} > \frac{5}{3}$, domalkalic.

Rang 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Rang 4: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Rang 5: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{1}{7}$, percalcic.

In Order 6, where feldspar is dominant over the lenads, only the first four Rangs will occur, in Order 7 only the first three, in Order 8 only the first two, and in Order 9 only the first one.

For femic minerals the general chemical characters of the bases are commonly expressed by the terms *ferromagnesian*, *calcic*, and *alkalic*. But three independent factors are not to be employed

1st 3 classes

Only Salic CaO and [illegible]alic $K_2O$ [illegible] $Na_2O$ [illegible] the CaO [illegible] allotted to [illegible] [illegible] and $K_2O$, $Na_2O$ [illegible]

in this system at one time, and it is necessary to combine two of the three to form a dual basis for a first subdivision. This is accomplished by uniting the first two and comparing the proportions of MgO, FeO, CaO′, and the *alkalies*, $K_2O'$, $Na_2O'$. In this case CaO′, $K_2O'$ and $Na_2O'$, are the parts of these rock components allotted to femic minerals. For the adjective expressing the first named quality, corresponding to *alkalic*, we propose to use the word *mirlic*, referring to the *m*agnesium, *ir*on and *l*ime. Upon a fivefold basis of comparison of these two sets of chemical constituents we form Rangs of Classes IV and V, although the more alkalic Rangs here provided are not yet known. They are:

See [illegible] Vol 2 p 5

The CaO, $Na_2O$ + $K_2O$ [illegible] rangs & subrangs & sections of Classes IV, V [illegible] lime

Rang 1: $\frac{(Mg, Fe)O + CaO'}{K_2O'' + Na_2O''} > \frac{7}{1}$, permirlic.

Rang 2: $\frac{(Mg, Fe)O + CaO'}{K_2O'' + Na_2O''} < \frac{7}{1} > \frac{5}{3}$, domirlic.

Rang 3: $\frac{(Mg, Fe)O + CaO'}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Rang 4: $\frac{(Mg, Fe)O + CaO'}{K_2O'' + Na_2O''} < \frac{3}{5} > \frac{1}{7}$, domalkalic.

Rang 5: $\frac{(Mg, Fe)O + CaO'}{K_2O'' + Na_2O''} < \frac{1}{7}$, peralkalic.

[illegible] rangs & subrangs in Classes IV & V the MgO & FeO are all the MgO FeO in the femic minerals [illegible] the [illegible] the total [illegible] the [illegible]

*Sections* of Rangs in Classes IV and V are necessary to recognize the varying proportions between the *ferromagnesian* and *calcic* characters of femic minerals, since the magnesium and iron are so closely associated chemically and characterize certain femic minerals free from calcium. For the word ferromagnesian, which is used in a somewhat loose manner in petrography, we propose to introduce the word, *miric*, to indicate strictly the *m*agnesium and *ir*on content in femic minerals, and to be mnemonic of these two metals.

These Sections of Rangs in Classes IV and V have been made on a fivefold basis as follows:

Classes IV & V.

Section 1: $\frac{(Mg, Fe)O}{CaO'} > \frac{7}{1}$, permiric.

Rangs according to the ratio $\frac{MgO + FeO + (Na_2O'' + K_2O'')}{CaO''}$

Subrangs " " $\frac{MgO}{FeO + (Na_2O'' + K_2O'')}$

Subrangs according to [illegible] $\frac{FeO}{Na_2O'' + K_2O''}$ " $\frac{MgO}{FeO + MgO''}$

Section 2: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}'} < \frac{7}{1} > \frac{5}{3}$, domiric.

Section 3: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}'} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 4: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}'} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Section 5: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}'} < \frac{1}{7}$, percalcic.

**Subrang.**—Subrangs are made on a basis of the special character of the variable or compounded chemical quality used in forming *Rang*. In Classes I, II and III this variable quality is in the ratio of alkalies, potash and soda, and the following subdivisions are recognized for Rangs I, II and III.

Subrang 1: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} > \frac{7}{1}$, perpotassic.

Subrang 2: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{7}{1} > \frac{5}{3}$, dopotassic.

Subrang 3: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 4: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{3}{5} > \frac{1}{7}$, dosodic.

Subrang 5: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{1}{7}$, persodic.

In Rangs IV and V of Classes I, II and III only three divisions are used because of the subordinate amount of alkalies. These Subrangs are:

Subrang 1: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} > \frac{5}{3}$, prepotassic.

Subrang 2: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 3: $\frac{\mathrm{K_2O}'}{\mathrm{Na_2O}'} < \frac{3}{5}$, presodic.

In Classes IV and V the variable quality is in the miric content. The alkalies are so preponderantly sodic that they do not require subdivision, and no distinction on a basis of the relative amounts of soda and potash are needed. For the present at least when femic minerals are said to be alkalic, it may be assumed that they are *presodic*. The divisions in Sections 1 and 2 of Rangs I and II are:

Subrang 1: $\frac{\text{MgO}}{\text{FeO}} > \frac{7}{1}$, permagnesic.

Subrang 2: $\frac{\text{MgO}}{\text{FeO}} < \frac{7}{1} > \frac{5}{3}$, domagnesic.

Subrang 3: $\frac{\text{MgO}}{\text{FeO}} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 4: $\frac{\text{MgO}}{\text{FeO}} < \frac{3}{5} > \frac{1}{7}$, doferrous.

Subrang 5: $\frac{\text{MgO}}{\text{FeO}} < \frac{1}{7}$, perferrous.

In Sections 3 of Rangs I and II and in other Rangs of Classes IV and V only *three* divisions are used, because of the subordinate amount of miric component. These are:

Subrang 1: $\frac{\text{MgO}}{\text{FeO}} > \frac{5}{3}$, premagnesic.

Subrang 2: $\frac{\text{MgO}}{\text{FeO}} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 3: $\frac{\text{MgO}}{\text{FeO}} < \frac{3}{5}$, preferrous.

*Sections of Subrangs.*—In certain Subrangs a division into Sections is necessary on account of the presence of various acid radicals or for other reasons.

In Classes I, II and III the salic mineral groups, quartz, feldspar and lenads, may be considered as: (*a*) silica and simple silicates, and (*b*) silicates combined with some other salt, or silicates containing some other acid, as Cl and $SO_3$. The latter are confined wholly to the lenads. This distinction is advisable here, rather than at Suborders, where it might otherwise fall, because of the great change in the mineralogical character of the lenad group induced by the presence of very small amounts of Cl and $SO_3$ (often less than 1 per cent.

of Cl yielding a notable amount of sodalite), and because, so far as has been observed, or seems *a priori* possible, the minerals of the sodalite group are only present in the sodic or sodipotassic Subrangs of Classes I, II and III. It may be pointed out that the sodalite minerals are also characterized by the presence of more $Na_2O$ than $Al_2O_3$.

The lenads to be contrasted are the simple silicates, nephelite and leucite, on the one hand, and the more complex silicates, sodalite and noselite, on the other. The former may be designated by the symbols *ne* and *lc*, and the latter by *so* and *no*, and the mnemonic syallables indicating these subgroups are *nel* and *son*.

The division will be needed only in Orders 6, 7, 8 and 9, which contain notable amounts of lenads, and will be fivefold in the sodipotassic, dosodic and persodic Subrangs of the peralkalic, domalkalic and alkalicalcic Rangs.

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} > \frac{7}{1}$, pernelic.
Section 2: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{7}{1} > \frac{5}{3}$, donelic.
Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.
Section 4: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5} > \frac{1}{7}$, dosonic.
Section 5: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{1}{7}$, personic.

In the dopotassic Subrangs of the Rangs just mentioned, and in the sodipotassic and presodic Subrangs of the docalcic Rangs, the division will be threefold:

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} > \frac{5}{3}$, prenelic.
Section 2: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.
Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5}$, presonic.

Since we have to deal here with the two acid radicals Cl and $SO_3$, we may distinguish between the sodalite and noselite rocks by dividing Sections 3, 4 and 5 of the fivefold division above, and Sections 2 and 3 of the threefold, on a threefold basis, which appears to be a sufficient subdivision. These Subsections will be as follows:

Subsection 1: $\frac{Cl}{SO_3} > \frac{5}{3}$, prechloric.

Subsection 2: $\frac{Cl}{SO_3} < \frac{5}{3} > \frac{3}{5}$, chlorsulphic.

Subsection 3: $\frac{Cl}{SO_3} < \frac{3}{5}$. presulphic.

Rocks belonging to each of the five Classes here proposed have been fully characterized mineralogically and chemically, as far as the preponderant salic and femic groups of minerals are concerned. There remains the consideration of the subordinate group, femic or salic, in each case, in order to complete the chemico-mineralogical classification of the rocks.

In Classes I and V since the preponderant group is present in extreme amount; the subordinate group is negligible, and no further division is necessary.

In Class II the subordinate group is present in notable amount, and is femic, while in Class III the femic group is given second place, after salic, so that in both cases we have to do with femic minerals, and further division will take place in this group and will be in general along the lines laid down in the preceding pages in the description of the divisions from Order to Subrang in Classes IV and V.

In Class IV the subordinate group is salic and is present in notable amount, so that further division will take place in this group, following the lines of division from Order to Subrang in Classes I, II and III.

It will furthermore be seen that, since in Classes II and IV the subordinate femic and salic minerals respectively are not equal to the preponderant salic and femic, it will not be necessary in these Classes to make the divisions, at least for the present, more than threefold, nor will it be useful to make in all cases the finer distinctions which obtain in the divisions based on the preponderant group of minerals.

In Class III, on the other hand, where the femic minerals are equal to the salic, and may in fact exceed them in some cases, the fivefold subdivision will be employed, and, as far as possible, the distinctions made in the first divisions of Classes IV and V will be recognized.

It may be noted here that it appears that in actual practice these later divisions will be used comparatively seldom in Classes II and IV, and it will be remembered that they do not exist in Classes I and V, but that they become important in the intermediate Class III.

**Grads** are based on the proportions of the standard minerals of the subordinate femic and salic groups in Classes II and IV. and of the femic group in Class III.

For Class II they are:

| | | | |
|---|---|---|---|
| Grad 1: | $\frac{P+O}{M} > \frac{5}{3}$, | femic silicate predominant, | prepolic. |
| Grad 2: | $\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$, | femic silicate and non-silicate equal | polmitic. |
| Grad 3: | $\frac{P+O}{M} < \frac{3}{5}$, | femic non-silicate predominant, | premitic. |

In Class III they are:

| | | | |
|---|---|---|---|
| Grad 1: | $\frac{P+O}{M} > \frac{7}{1}$, | femic silicate extreme, | perpolic. |
| Grad 2: | $\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$, | femic silicate dominant, | dopolic. |
| Grad 3: | $\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$, | femic silicate and non-silicate equal | polmitic. |
| Grad 4: | $\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$, | femic non-silicate dominant, | domitic. |
| Grad 5: | $\frac{P+O}{M} < \frac{1}{7}$, | femic non-silicate extreme, | permitic. |

In Class III it is also necessary to discriminate further between pyroxene and olivine, corresponding to the Suborders of Orders 1, 2 and 3 of Classes IV and V. This will be necessary only in Grads 1, 2 and 3 of Class III. They are:

| | | | |
|---|---|---|---|
| Section 1: | $\frac{P}{O} > \frac{5}{3}$, | pyroxene predominant, | prepyric. |
| Section 2: | $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$, | pyroxene and olivine equal, | pyrolic |
| Section 3: | $\frac{P}{O} < \frac{3}{5}$, | olivine predominant | preolic. |

In Class IV the subordinate minerals belong to the salic group. Their division into Grads is of the same kind as that forming Orders in Classes I, II and III, but since their amount is considerably smaller than in rocks of these Classes, the division is on a threefold basis, resulting in five Grads, as follows:

| | | | |
|---|---|---|---|
| Grad 1: | $\frac{Q}{F} > \frac{5}{3}$, | quartz predominant, | prequaric. |
| Grad 2: | $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$, | quartz and feldspar equal, | quarfelic. |
| Grad 3: | $\frac{Q \text{ or } L}{F} < \frac{3}{5}$, | feldspar predominant, | prefelic. |
| Grad 4: | $\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$, | feldspar and lenads equal, | lenfelic. |
| Grad 5: | $\frac{L}{F} > \frac{5}{3}$, | lenads predominant, | prelenic. |

SUBGRADS are formed on the general chemical character of the bases of the minerals employed to form Grads, and bear the same relation to the latter that Rangs bear to Orders. On account of the smaller amount of the minerals involved in Classes II and IV it is not thought desirable to give the distinctions as great a taxonomic value as when the preponderant minerals are concerned, and so they are made the basis of Subgrads rather than of a new taxonomic division.

In Class II the subordinate minerals being femic the chemical divisions are similar to those forming Rangs in Classes IV

modification Journ Geol. Vol 20 p 55.
Classes II & III
Subgrads by ratio: $\frac{MgO + FeO + (Na_2O'' + K_2O'')}{CaO''}$
Sections of Subgrads by ratio $\frac{MgO}{FeO + (Na_2O'' + K_2O'')}$
Subsections Subgrads by ratio $\frac{FeO}{(Na_2O'' + K_2O'')}$

and V, but are on a threefold basis because of the smaller amount of femic minerals, as follows:

Subgrad 1: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} > \frac{5}{3}$, premirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O''} < \frac{3}{5}$, prealkalic.

In Class III Subgrads are formed on a basis of the chemical characters of the femic minerals by analogy with those of Class II, but because of the greater proportions of these minerals the division is on a fivefold basis, yielding:

Subgrad 1: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} > \frac{7}{1}$, permirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} < \frac{7}{1} > \frac{5}{3}$, domirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 4: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} < \frac{3}{5} > \frac{1}{7}$, domalkalic.

Subgrad 5: $\frac{(Mg, Fe)O + CaO'}{K_2O' + Na_2O'} < \frac{1}{7}$, peralkalic.

In Class IV the minerals forming Grads are salic, and since they are subordinate to the femic it is advisable to make only three divisions instead of five, as follows:

Subgrad 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{5}{3}$, prealkalic.

Subgrad 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Subgrad 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5}$, precalcic.

*Sections of Subgrads* in Class III are established because the amount of femic minerals is equal or nearly equal to that of the salic, and it is desirable to make further chemical distinctions as in the case of Sections of Rangs in Classes IV and V. The divisions are the same in both cases, and are based on the proportions of miric and calcic constituents. They need only be used in Rangs 1, 2, and 3.

Section 1: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} > \frac{5}{3}$, premiric.

Section 2: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 3: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} > \frac{3}{5}$, precalcic.

*Subsections* of Sections 1 and 2 are based on the proportions of magnesic and ferrous components as in the case of Subrangs in Classes IV and V. They are:

Subsection 1: $\frac{\mathrm{MgO}}{\mathrm{FeO}} > \frac{5}{3}$, premagnesic.

Subsection 2: $\frac{\mathrm{MgO}}{\mathrm{FeO}} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subsection 3: $\frac{\mathrm{MgO}}{\mathrm{FeO}} < \frac{3}{5}$, preferrous.

It is understood, of course, that all the divisions just described are not needed, as has been explained in regard to those based on the preponderant group of minerals. Thus a calcic Subgrad is not needed in a Grad with dominant lenads. In such cases it is simply inactive.

### THE RÔLE OF ACTUAL MINERAL DEVELOPMENT AND TEXTURE IN ROCK CLASSIFICATION.

The methods employed in forming *Classes*, *Orders*, *Rangs*, *Grads*, and their subdivisions are distinctly chemico-mineralogical and chemical, the minerals considered being those defined as *standard*. These divisions are applicable to magmas regardless of their mode of solidification or crystallization. The classification so far is purely magmatic.

The chief object attained up to this point by the system proposed is the uniting of all igneous rocks having like chemical compositions into divisions or groups which conform to our present conceptions of chemical petrographical unity. And it has been our endeavor at the same time to prepare such a scheme of subdivision that should demands be made for greater chemical discrimination by future petrographers, further subdivision may be carried on as an elaboration of the classification here suggested.

But the problem before us being the classification of igneous rocks, there remains the method of treatment of the rocks themselves. This involves the consideration of the minerals actually present, including the aluminous ferromagnesian minerals, which occur in the great majority of igneous rocks and often form the preponderant constituents. It also involves the consideration of the texture of the rock, which is perhaps the most obvious feature, as well as the legend of its physical history. The elimination of the aluminous ferromagnesian minerals from the system of magmatic classification just described is frankly for its simplification. The exact expression of the chemical magmatic units which would be required should these minerals be introduced would be so intricate as to be practically useless. It is conceivable that an exact mathematical expression involving all of the variable factors or interchangeable combinations, such as are represented by the compositions of biotites, amphiboles, and augites, is possible, but it would be beyond the reach of petrographers generally.

The actual mineral development of an igneous rock is to a great extent so related to the texture that the two are interdependent, which naturally follows from their both being controlled to a large degree by the physical conditions attending eruption and solidification. But since these relations as well as the physical conditions are far from simple, it is therefore necessary, for the present at least, to treat the mineral and textural development of igneous rocks separately.

In petrographical classifications in present use either the actual composition or the texture is made the basis of subdivision, and the other is used for further subdivision. And it is recognized that there is variation in either case within the limits of petrographical divisions, however constituted.

This may be illustrated by the following examples:

1. Let us consider the case of somewhat similar rocks having like textures but somewhat different mineral compositions which have been classed together under one name on a basis of texture, and subsequently separated on a basis of mineral differences, the gabbros. Among several of these rocks with phanerocrystalline granular texture there are those with hornblende, or mica, or olivine, and they are known as hornblende-gabbro, mica-gabbro, and olivine-gabbro.

2. There is a case of a number of rocks having nearly the same mineral composition (labradorite, augite, olivine, and magnetite) and called basalt, which possess quite different textures, such as evenly granular, ophitic, intersertal, porphyritic, or microlitic glassy.

We can see strong grounds for both of these methods of classification, and each may serve an important purpose in petrographical work. There are instances in which one method of correlation is more valuable than another. Freedom of choice should be allowed if consistent with definiteness and stability of the system of classification.

For these reasons the variable characters of each petrographical unit established by the system of classification we propose, which characters are results of the conditions attending solidification, or crystallization, are treated in a different manner from the chemical characters. They are treated as variable factors in the system, although inherent and persistent qualities of a particular rock. They are assigned the rôle of qualifiers of the magmatic units wherever there is need of further subdivision. They consequently appear in the production of a systematic nomenclature, which is an integral part of comprehensive classification.

### *Actual Mineral Composition.*

Let us first consider what minerals may actually be developed in rocks and what relations they bear to the standard minerals which are used to express the chemical composition of a magma unit. And let us assume that the rock is holocrystalline. Those cases in which more or less of the magma becomes glass will be discussed afterward.

For convenience we introduce two terms which have suggested themselves as substitutes for the cumbrous and oft-repeated expressions, *standard mineral composition* (that calculated from the rock analysis) and *actual mineral composition*. For the first we propose the word *norm*[1], and for the second the word *mode*.[2] The standard minerals which make up the norm are to be called the *normative*[3] minerals, not the *normal* ones, since the latter adjective has the meaning of usual or common.

The questions arise, how far does the *mode* of a holocrystalline rock correspond to the *norm*, and what distinctions are necessary among rocks belonging to one magma unit because of differences among them due to their actual mineral composition?

There are all possible grades of correspondence between the mode and norm of rocks when the whole range of rocks is taken into account, but when this inquiry is applied to separate magmatic units the answer must be modified according to the kind of magma considered.

For example, some magmas of extremely simple composition crystallize in one manner only, so far as our present knowledge goes. Those composed of almost pure silica form only quartz with negligible amounts of other things. Magmas whose norm is quartz and orthoclase will form rocks with these minerals as the *mode*. Magmas whose norm is a simple rock-making mineral, as labradorite or olivine, will crystallize into rocks composed of one of these minerals only.

Consequently rocks belonging to magmatic divisions characterized by extreme amounts of standard quartz, orthoclase, albite or nephelite; of the lime-soda-feldspars; of diopside or hypersthene, or olivine, or magnetite, will have actual mineral compositions very closely corresponding to the calculated norm. That is, the preponderant minerals actually crystallized will be

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[1] A rule, pattern, model, authoritative standard.—*Century Dictionary*.

[2] The natural disposition or manner of existence of anything.—*Ibid*.

[3] Establishing or setting up a norm.—*Ibid*.

the same as those calculated from the rock analysis. Variations may occur in the kind of subordinate minerals for reasons which will be explained presently.

On the other hand, magmas containing nearly equal amounts of both salic and femic molecules or dominant amounts of the latter may develop alferric (aluminous ferromagnesian) minerals to such an extent as to prevent the crystallization of any appreciable amount of the standard minerals. A well-known example of this is the hornblendite of Brandberg, in Gran, Norway,[1] a rock of Class III, which crystallized as almost pure hornblende.

A similar magma, however, may crystallize into minerals corresponding closely to the norm, as in the case of the nephelite-basanite of Colfax county, New Mexico.

It follows from this that in some divisions of the system the actual mineral composition of holocrystalline rocks will accord very closely with their norms, while in others it may or may not. And in these cases there may be various degrees of correspondence between the mode and norm.

In general a number of degrees of correspondence between the actual and the standard mineral composition of igneous rocks may be recognized. They may be expressed as follows:

1. COMPLETE OR ALMOST COMPLETE ACCORD BETWEEN THE MODE AND NORM.—In the first case the two correspond exactly both qualitatively and quantitatively. By *almost complete* accord is meant one in which all the principal minerals recognized in establishing the norm are actually present in the rock in approximately the same proportions as in the norm, or else standard minerals not calculated in the norm or non-standard minerals are present in such small amounts as not to affect the position of the rock in the system. In these cases of complete or almost complete accord the rock may be said to have a *normative mode*.

A *normative mode* may be defined as one in which the *actual mineral composition* of the rock is so nearly the same as the *standard mineral composition* calculated from the analysis that either may be used to classify the rock correctly.

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[1] *Loc. cit.*

A special and important case of accord between norm and mode is that of the highly feldspathic rocks. It will have been noticed that in the list of standard minerals no reference was made to the plagioclase feldspars intermediate between albite and anorthite (oligoclase, andesine, labradorite, bytownite), nor to the various alkali-feldspars, other than orthoclase and albite, such as microcline and soda-microcline (anorthoclase). This is for the following reasons :

The feldspars present in a rock are seldom of only one kind, several distinct species being present usually, this being true especially of the plagioclases.

The individual plagioclase crystals are frequently zonal, so that an exact determination of the relative amounts is a matter of difficulty if not of impossibility.

When orthoclase, albite and anorthite molecules are present, in rocks of identical chemical composition, the possibilities of combination of these as actual minerals are many. Thus we may have an orthoclase-andesine rock, in which all the albite has crystallized with the anorthite, or an anorthoclase-labradorite rock, where some of the albite has crystallized with the orthoclase.

We therefore classify rocks, as far as the feldspars are concerned, by the calculated molecules of orthoclase, albite and anorthite, irrespective of their actual mineral combinations. The proportions of these will give the *mean composition* of the feldspars. Any of the possible combinations will then be *normative* in the sense above, provided that none or only a negligible amount of the feldspathic molecules crystallize as lenads.

If it should be desired to indicate in the name which combination is actually present, this can be done by the use of the appropriate feldspar name, as described later. Since, however, the albite molecules crystallize with those of anorthite, if these are present in any quantity, it will be necessary to distinguish only the cases in which the albite molecule has crystallized with that of orthoclase, as soda-orthoclase.

2. APPRECIABLE DIFFERENCE BETWEEN THE NORM AND MODE. —Abnormative minerals (whether standard or not) are in such

cases present in quantities which are not negligible, so that the rock cannot be classified directly from the minerals actually present without consideration of the mutual changes involved in the diverse crystallization of the various minerals possible. Such modes may be called *abnormative.*

The abnormative modes may be referred to two kinds, of which the second is by far the most important and common, though the first naturally precedes it in the discussion.

*a*) The minerals present may be all standard, but differ from those of the norm either in kind or relative proportions, or both. This case is generally due to shifting of the $SiO_2$ and $TiO_2$, and may be illustrated by these instances: quartz and leucite crystallize instead of orthoclase, albite instead of nephelite with leucite, as in leucite-basanites and tephrites, quartz with olivine as in quartz-basalts, hypersthene with nephelite, titanite instead of perofskite or ilmenite, the silica in this case coming from normative feldspar molecules. The normative corundum may also form muscovite with molecules of orthoclase and water.

These cases, it will be seen, affect the mineral molecules of oxides capable of combining in more than one proportion with $SiO_2$, namely $K_2O$, $Na_2O$, $(Fe,Mg)O$. All of these modifications are within the range of the standard salic and femic minerals, and if not accompanied by notable amounts of non-standard minerals (as augite or hornblende), may be called respectively *salic*, *femic*, or *salfemic* abnormative modes, according as the abnormative minerals belong to one or the other or both groups.

*b*) The mode may differ from the norm through the presence of alferric (aluminous ferromagnesian) minerals, augite, hornblende, biotite, garnet, etc.

As is explained in the Part on Calculation, and as is evident on consideration of the subject, the formation of any of these minerals involves changes in some, if not all, of the standard minerals calculated as present in the norm. While minerals of both the standard salic and femic, and non-standard alferric groups are involved, yet it will be sufficient to characterize these modes as *alferric.*

In both the above cases *a* and *b* it is evident that, given the knowledge of the norm and the mutual interrelations between the rock-making minerals which will be explained in the Part on Calculation, it is only necessary to know the amount of abnormative minerals, whether standard or not, to be able to ascertain the changes from the norm which their presence involves. These distinguishing minerals therefore may be called *critical* ones.

The question of how far quantitative distinctions based on the amounts of the critical minerals are to be introduced into the classification is discussed in connection with the nomenclature.

Having thus explained the various relations possible between norm and mode, it will be well to summarize the correspondence observed in fact among the different Classes. It is obvious that no one systematic method of calculation of mineral composition from the chemical can correspond with all the varying possibilities of actual mineral development. The method adopted by us, however, being founded on the most frequently observed mineral relations in igneous rock and on the most generally applicable principles, should yield norms which correspond with the mode in the majority of cases.

This is a point which can only be tested by appeal to the literature of petrography, and comparison of the calculated norms with the modes as furnished by the descriptions. We have, it may be stated here, tested our proposed method in regard to this point very thoroughly upon many hundreds of rock analyses, and especially by means of a collection made by one of us (H. S. W.) of all analyses of igneous rocks which have been published since 1883, amounting to over three thousand.[1]

This comparison shows that the accord between norm and mode is complete or nearly so in the very great majority of

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[1] It is hoped that this collection, which will show the norm in every reliable case, will appear shortly after the publication of the present paper, and it will serve as a general illustration of the system. Although not as yet available to others, it has been appealed to as a practical check throughout our discussions, so that the system cannot be regarded as merely academic, but as having been tested at every possible point.

rocks of Class I and in the greater portion of those of Class II, these two classes comprising over three-quarters of the known or analyzed igneous rocks of the globe. The accord is also very good in Class V, which includes but few rocks. Classes III and IV show less constant accord, as is to be expected in view of their composition. The results of our proposed method of calculation may therefore be regarded as satisfactory.

VARIETIES.—It is evident that within the range of possibie variations in each of these modes for a given magma unit, there may be mineralogical distinctions among the quite subordinate components, and that it may be desirable to recognize these differences as distinguishing features of rocks. The method of accomplishing this is by considering the several subdivisions upon this basis as *Varieties*, more specifically *Modal Varieties.*

A *Modal Variety* of a petrographical unit of whatever degree, such as Class, Order, Rang, etc., may be defined as a rock having a mode with a slightly different development of the quite subordinate component minerals.

For example, a rock belonging to Class I composed of an extreme amount of feldspar (5th Order) may have 10 per cent. of nephelite actually crystallized, whereas the norm contains no nephelite, the difference having been brought about by the development of a small amount of hypersthene or of hornblende instead of olivine.

The development of a small amount of hornblende, or of biotite, in a rock with a normative mode also constitutes a Modal Variety. The presence of small (not notable) amounts of rare or otherwise noteworthy minerals may also thus be recognized as varieties.

*Indeterminable Modes.*—Rocks not completely crystallized, containing glass base, and those which for any reason do not permit the determination of all the component minerals, must be classified in the first instance in each case by comparison of the observed minerals with the norm calculated from the chemical analysis of the rock, and subsequently, by analogy with holocrystalline rocks of similar chemical composition whose texture is somewhat like that of the rock in question and whose actual mineral components can all be determined.

### *Texture.*

The terms *structure* and *texture* are commonly used in petrography as synonyms, although efforts have been made to discriminate between them. It seems to us desirable to employ them in different senses, and we propose to limit the use of the term *structure* to those large features of rock bodies which are known as columnar structure, spheroidal parting, platy parting, bedding, brecciation and others. And we use *texture* for the material features of rocks exhibited by the mineral components and by the groundmass of dense or glassy rocks, whether they are viewed megascopically or microscopically. These features are the expression of the mutual relations of the mineral particles or vitreous portions of rocks.

The texture of igneous rocks is one of their most variable characters. It depends in very large degree upon extraneous conditions influencing the consolidation of the magma and in far less degree upon certain relationships between the forms of the rock-making minerals. The factors influencing it are many. Nearly the whole range of textures may be developed in rocks from a single magma consolidating under different conditions. Consequently the use of texture as a primary factor in the classification of igneous rocks can only result in the wide separation of things alike in chemical and mineral characters, which, on the grounds discussed in the preceding pages, are believed to be of greatest systematic importance.

Its use as a prominent factor in classifications has been in most cases coupled with assumptions or assertions known to be by no means strictly in accordance with facts. When such a use of texture is to be made, it is necessary to assume that all rocks possess some one of the few textures at present employed in classification, such as the granular, porphyritic, trachytoid, glassy, etc. This further requires that these textures be so broadly defined that they are robbed of much of their natural descriptive value, or that the definitions be so restricted that they are not appropriate to many of the rocks to be classified.

It has been common to assume a fictitious dependence of texture upon geological occurrence, ignoring other conditions which are plainly of much influence; as, for example, the assumption that granular rocks are plutonic or deep-seated, or, from the converse point of view, that effusive rocks must be partially glassy, or trachytic, or porphyritic.

Less often definitions of texture have involved assumptions of their origin only partially in accord with the facts.

In some cases rocks have been classified on a basis of only part of their texture, as when in certain porphyritic rocks the texture of the groundmass alone has been taken into consideration.

It appears to us that the use of texture in previous petrographic classifications has, on the one hand, weakened the systems by rendering them unnecessarily artificial and illogical, and, on the other hand, has prevented the natural application of certain textural terms. The classificatory rôle assigned to texture in this system is that of a qualifier of any of the various divisions based upon chemical and mineral characters. We present certain general considerations of rock textures which may aid in securing for the various factors which enter into texture a recognition which it seems to us they have not thus far commonly secured. The discussion does not profess to be complete as to all rock textures but simply takes up some of the more prominent textures and discusses their essential properties and relations.

When we consider the texture of igneous rocks we find that it may be separated into three factors, which though not in all cases absolutely distinct from one another are so to a very considerable extent. They are:

I. *Crystallinity.* The degree of crystallization.

II. *Granularity.* The magnitude of the crystals.

III. *Fabric.* The shape and arrangement of the crystalline and noncrystalline parts.

Various textural modifications of igneous rocks may be distinguished from one another, but it is understood that in this respect, as in all others, there are all gradations between different textures. Moreover, all known textures are not developed within every known magma unit, and some textures are specially frequent in rocks of particular compositions.

I. CRYSTALLINITY.—The degree of crystallization attained by an igneous rock is measured by the relative amounts of crystallized and glassy portions. Perfectly glassy rocks are very uncommon, since most obsidians abound in microscopic crystals, while many lavas that are almost completely crystallized contain small amounts of glass. Most rocks are holocrystalline, and all gradations between the extremes exist.

Distinctions that have been based on crystallinity are of two sorts: one an absolute distinction based on the known absence or presence of glass base or matrix, resulting in (*a*) *holocrystalline*, (*b*) *hypocrystalline, or partly crystalline*, and (*c*) *holohyaline, or completely glassy*, rocks. The other sort of distinctions are less definite, being based on the megascopic appearance of the rock, but they are of great practical value. They are (*a*) *phanerocrystalline*, (*b*) *aphanitic*, and (*c*) *vitreous*.

*Phanerocrystalline* rocks are generally *holocrystalline*.

*Aphanitic* rocks are in some instances microscopically *holocrystalline*, in others *hypocrystalline*. Because in some cases it is not possible without microscopical study to determine the presence or absence of glass matrix, it is extremely useful to refer a rock to this textural division. It is discussed again in the next phase of the subject.

*Vitreous* rocks are *hypohyaline* or *holohyaline*.

II. GRANULARITY is the quality based on the absolute size of the crystals, which, when all igneous rocks are considered, range from microscopic sizes to megascopic ones measured in feet. The quality derived from the relative sizes of the crystals in one rock may be considered as a phase either of granularity or of fabric.

Distinctions based on differences in the absolute size of the grain of rocks have never been sharply defined, because the crystals in an igneous rock are never of uniform size. They vary among themselves considerably in most cases, and it is the average size which is in mind when reference is made to the grain of a rock.

The most important distinction made on this basis is for practical purposes, namely, that between *phanerocrystalline* (phaneric) rocks, whose crystals may be seen by the unaided eye, and *aphanitic* or *cryptocrystalline* rocks, whose crystals are not apparent megascopically. The term *aphanitic* is the better one to use in most cases, because the term cryptocrystalline implies the holocrystalline character of the rock, which may not have been determined. This fact is well expressed by the negative term aphanitic.

*Phaneric* (phanerocrystalline) rocks are commonly divided into *coarse-grained*, *medium-grained*, and *fine-grained*. But for these terms no limits have been set except those suggested by Zirkel,[1] namely, that the first include all those whose average grain is larger than the size of peas; that the second range from the size of peas to that of millet seeds; and that fine-grain include those of the size of millet seeds and smaller. Translating this into millimeters we would suggest the following scale:

Fine-grained rocks, average grain 1 millimeter or less.

Medium-grained rocks, average grain 1 to 5 millimeters.

Coarse-grained rocks, grain more than 5 millimeters.

*Aphanitic* rocks have never been systematically divided on a basis of the size of the microscopic crystals, though terms borrowed from the megascopical nomenclature have been adopted to fit the case. These are: *microcrystalline*, which is equivalent to microphanerocrystalline, and applies to textures whose grains can be seen with a microscope; and *microcryptocrystalline*, which includes textures whose grains cannot be seen with a microscope, but which are recognized as present by the exhibition of aggregate polarization between crossed nicols.

In place of distinctions corresponding to coarse, medium,

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[1] *Lehrbuch der Petrographie*, Vol. I, p. 456, 1893.

and fine-grain, which are useful when megascopically applied, it is possible to describe the average measured diameter of microscopic crystals. But there appears to be no demand for systematic subdivisions based on the magnitude of these minute textures.

Textural distinctions based on the relative sizes of the crystals in one rock recognize (1) *evenly granular* or *non-porphyritic* rocks, and (2) *porphyritic* rocks. These distinctions cannot be sharply drawn, because, as already said, it almost never happens that all crystals in a rock are the same size. Moreover, there is a great variety of ways in which differences of size in crystals may exhibit themselves.

The difference of size which constitutes *porphyritic* texture may be defined as that in which the size of some crystals is so much larger than that of a sufficient number to form a matrix for the first, that the larger ones appear notably distinct from the matrix or groundmass. There are *porphyritic* rocks with phaneric (phanerocrystalline), aphanitic, or glassy, groundmasses, the phenocrysts being megascopically notable. And there are microporphyritic aphanitic or glassy rocks, in which the phenocrysts are not megascopically notable, although they may be visible.

Granular and porphyritic textures may also be considered as modifications of the fabric.

III. FABRIC.—The *arrangement of the crystalline* and *non-crystalline* parts of a rock, or its *fabric*, as we propose to call it, is dependent on (1) the shapes of the crystals, and (2) their positions with respect to one another and to the glass base when present.

When considered with reference to all the minerals in the rock the fabric of most rocks is so complex that no simple expression is applicable to it, and nearly all the formal relations which it is customary to distinguish as different rock textures frequently exist in one rock. However, it usually happens that certain features dominate in each case while others may be quite insignificant though present. Hence we may again disregard those which do not occur to a notable extent and use those which predominate as the means of discrimination, that is, as a basis for textural subdivision.

1. As to the shape of the constituent crystals, there are two distinctions of a general nature:

(*a*) *Automorphic*[1] (idiomorphic) forms, in which the crystal form has been developed more or less perfectly.

(*b*) *Xenomorphic*[1] (allotriomorphic) forms, in which the proper crystal form has not been developed owing to interference from outside influences.

These latter forms are of two kinds: one caused by the interference of adjacent crystals, the commonly recognized case in holocrystalline rocks; the other is caused by outward forces acting in the liquid from which crystallization has taken place, which produce irregularly shaped crystals peculiar to microscopic growths in the more siliceous glasses, but not confined to them.

Other distinctions of shape depend on the particular forms of the crystals, whether equidimensional, tabular, prismatic, or otherwise.

2. The arrangements or positions of crystals with respect to one another may be grouped under several heads:

A. *Juxtaposition.*—In this case, although subordinate minerals may be enclosed in the preponderant ones, the preponderant minerals are adjacent to one another, and the following divisions based on the shape of the crystals are recognized:

*Granular*, in which adjacent crystals have nearly the same size, so that the rock appears to be made up of more or less uniform grains. According to the form of the individual crystals the rock is said to be:

*a*) *Xenomorphic granular*, in which the crystals are xenomorphic and equidimensional. This is commonly called "granitic" fabric.

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[1] We adopt the use of *automorphic* and *xenomorphic* instead of *idiomorphic* and *allotriomorphic*, as they have undoubted priority, Rohrbach having used the former in 1886 (*T. M. P. M.*, Vol. VII, p. 88), while Rosenbusch introduced the latter terms in 1887. Rohrbach's terms have the further advantage of being shorter.

*b*) *Hypautomorphic granular*, in which some of the crystals, or parts of some crystals, are automorphic, while others are xenomorphic.

*c*) *Panautomorphic granular*, in which all the crystals possess their proper forms more or less perfectly. Of course absolute automorphism cannot exist in a compact, continuous rock. The precise character of this fabric depends on the kinds of minerals present and on their particular habit. It is, therefore, different in rocks of different compositions so far as observed.

*Tabular or prismatic fabric.*—There is further modification of it in case the shapes of some of the minerals are *tabular* or *prismatic*. In such cases there may be distinctions according as there is: no definite arrangement of plates or prisms, which stand in all positions; or a regular arrangement in more or less parallel directions (*fluidal* or *parallel fabric*), or in more or less radiatng directions (*radiate fabric*).

B. *Interposition* (inclusion).—The arrangements of crystals referred mainly to inclusion of one by another are of two principal kinds:

*a*) *Graphic fabric.*—One in which two minerals mutually inclose one another, by interpenetration. This is shown by the parallel orientation of several parts of each mineral. The familiar example is the *graphic* intergrowth of quartz and feldspar.

*b*) *Poikilitic fabric.*—The second kind of interposition fabric is that in which one mineral acts as a matrix for one or more kinds of other minerals which do not possess parallel orientation. This is exhibited by various rocks, in some of which hornblende crystals form the matrix, in others orthoclase, in others quartz.

*Ophitic fabric* is a special case of poikilitic, in which plagioclases are inclosed in augite crystals, the feldspars being relatively large when compared with the areas of augite.

C. *Porphyritic fabric* is one characterized by the presence of crystals surrounded by a matrix noticeably distinct from them. These crystals are known as *phenocrysts*. The matrix or groundmass may be crystalline or glassy. The phenocrysts are megascopic in some cases, and microscopic in others. When they are microscopic in a glassy matrix the fabric is called *microlitic glassy*.

D. *Orbicular fabrics.*—There are complex fabrics so frequent and so characteristic that they have formed bases for textural divisions. They are:

*a*) *Spherulitic*, allied to the microlitic fabric in some cases in that it can be traced to special forms of microscopic crystallization, consisting of radiating prisms. It is further allied to porphyritic fabric, in that it may be developed locally in the magma and produce scattered spherulites of notable size, and having the appearance of phenocrysts.

*b*) *Spheroidal*, closely like spherulitic in some cases, where there is crude radial arrangement of crystals, but quite different from it in others in which there are concentric granular shells. A somewhat diverse form of aggregate crystallization occasionally developed in phaneric rocks.

HETEROGENEOUS TEXTURES produced by more or less heterogeneity in the magma are distinguished by marked variability of (*a*) fabric, or (*b*) composition.

*a*) *Eutaxitic texture.*—Variability of fabric is exhibited by some banded or streaked lavas (rhyolites) in which alternate layers of rock exhibit different degrees of crystallinity or different arrangements of crystals. Variability of texture on a large scale is often exhibited by phaneric rocks of similar composition (granitic pegmatites).

*b*) Variability of composition may not strictly belong to the discussion of the texture of rock, but the two are intimately blended, and the treatment of the matter in this place may be justified. It results in *banded textures*, approaching gneissic, and is exhibited in certain gabbros; also in irregularly streaked textures, known in German as *Schlieren*, which may be called *schlieric textures*.

In classifying rocks on a basis of textural differences we have considered the fabric, or the shape and arrangement of the crystals, as more fundamental than the crystallinity or granularity, for the reason that it is more clearly a function of the composition of the magma, since it depends upon the shapes of the crystals which are often characteristic of particular minerals which preponderate in rocks of certain compositions.

On the other hand it is possible for any magma to attain any degree of crystallinity, although all degrees, from glassy to holocrystalline, are not known for all kinds of magmas. In the same way any magma may develop any grade of granularity, although some grades are oftener observed in certain kinds of magmas than in others.

The method of recognizing these differences of texture and of introducing them into the classification is referred to the nomenclature, where it will be fully stated.

# PART II.

## NOMENCLATURE.

Having outlined the system of classification proposed by us, it is necessary to present and discuss the nomenclature which we have constructed for its expression and use.

As already pointed out, the present system of nomenclature is most unsatisfactory, for the reasons that it furnishes no distinctions between names of different values (one termination alone being regularly used), nor indication of the relations of any of the groups.

Furthermore, since the system of classification here proposed is based on relations and principles quite distinct from those in present use, the old names cannot be employed for the new divisions. This is obvious for the reason that the new divisions do not cover the same concepts or characters as the old ones, and because the use of an old name with a new meaning is to be shunned as leading to grave misunderstanding and confusion.

Rock names, like those of any other system of nomenclature, are, or should be, composed of two parts, with distinct functions, viz., the *body* or *root*, and the *termination*. The former expresses either directly, or by implication or connotation, the character of the object or group of objects to which it is applied, and the latter indicates the place of the object or group in the co-ordinated system, from the broadest to the smallest division. Each separate division, from the largest to the smallest, should have a distinctive appellation, precluding confusion with others, and indicating at once its relative place in this system and its character. The names should be mnemonic, if possible, expressing the idea to be conveyed, short, euphonious, and not liable to be mistaken for one another.

In accordance with the principles just stated, we have constructed names for the various magmatic divisions which have been explained in the preceding pages on classification. In addition to these it will be necessary to employ qualificatory terms to express the variable characters of mineral composition and texture, which, with the appropriate magmatic name, will apply to the rocks themselves. The nomenclature, then, will be to a certain extent polynomial. These qualifiers may be applied at any point in the system.

### MAGMATIC NAMES.

TERMINATION.—It is possible to indicate the place of any given rock name in a system by employing only one termination and by varying the root of the word, which then alone indicates at the same time both the character of the group and its relative position in the system. Thus, with the single termination *-ite* the family name, foyaite, expresses the concept of rocks formed essentially of alkali-feldspar and nephelite, while smaller divisions of this are indicated by such names as laurdalite, litchfieldite and lujavrite.

But this method is very unsatisfactory and primitive, in that it does not avail itself of the very powerful aid afforded by such possible terminations as would in themselves give considerable knowledge of the group named. Furthermore, while feasible with a small number of names, such a method involves a great tax on the memory, especially with the rapid growth of our knowledge of rocks and of new rock types, and the necessity for new names.

These serious objections to the use of but one termination have so far been scarcely recognized, and this great defect in present nomenclature is one cause of much of the prevalent outcry against the multiplication of rock names.

To indicate the relative place of the various divisions in the system, from Class to Subgrad, we have adopted a set of terminations which are to be used invariably with their respective divisions. We have endeavored to select those which are at the same time: mnemonic in suggesting the relative positions of the divisions ; euphonious ; not in previous use to any great extent ; and as far as possible adapted to use in all European languages.

The termination -ite is rejected because it is already in use, not only in petrography but in mineralogy, to which latter science, as having a prior claim, we suggest that it be restricted. The terminations proposed are as follows:

| | | | |
|---|---|---|---|
| Class, | -ane. | Subclass. | -one. |
| Order, | -are. | Suborder, | -ore. |
| Rang, | -ase. | Subrang, | -ose. |
| Grad, | -ate. | Subgrad, | -ote. |

These terminations were selected after trial of many that were suggested. The distinctive consonants, *n*, *r*, *s*, *t*, are in their alphabetical order, suggesting the sequence of the taxonomic divisions to which they refer. The vowels, *a* and *o*, were considered best to indicate the distinctions between each principal division and its subdivisions. And the final *e* is added in English to lengthen the sound of these vowels, but it may be omitted when the words are used in other languages.

The name of a magma belonging to a *Section* of any given division will receive the termination of that particular division preceded by the letter *i*, since it occupies the same relative position in the scheme as the division in question, although of somewhat different taxonomic character.

ROOT.—In choosing the root of the name two methods are available. This part may be a syllable or syllables derived from local or personal names or chosen arbitrarily, giving only by connotation an idea of the character of the group named; or it may be composed of syllables which will of themselves, by proper selection on mnemonic grounds, give an idea of the character.

The latter method would seem at first sight to be the better, since it apparently involves less tax on the memory. We have, however, made many attempts at the construction of such name roots, giving them practical trials at all points of the scheme, but have been forced to reject this method for all divisions except that of Class, for the following reasons:

1. The names are apt to be excessively long and cumbrous, especially in the smaller divisions.

2. While the distinctions can be readily seen on paper, yet close attention must be paid to each syllable and even to each letter, and in spoken language the names are so similar as to be confused with each other.

3. As a consequence, the mnemonic quality, which is the great theoretical advantage of this method, is very seriously diminished, especially in the smaller divisions.

4. The adoption of this method involves a fixation or lack of elasticity in the nomenclature, which would be fatal to it, if the need arose for any change either in the method of arriving at the divisions or in their number, since this would involve a corresponding change in the nomenclature.

We have, therefore, except for Classes and Subclasses, adopted roots derived from names of localities, taking advantage of the fact that there are at present many of these in present petrographical nomenclature with connoted magmatic ideas which are readily adaptable to our purpose. Thus with the root *nordmark* is connoted the idea of an alkali-feldspathic rock, with *miask* that of a rock composed essentially of alkali-feldspar and nephelite. These are, it is true, not the only connotations of these names, since in both of them are also implied ideas of texture.

In the names suggested subsequently we have endeavored to adhere to the following principles in the selection of roots.

*a*) They should be adjusted to the relative position of the divisions to which they are applied. That is, the roots of names which are at present in use for large rock groups, or which were proposed by the author for such groups, are used for the larger divisions, such as Rangs, while those which have at present, or were originally given, narrower or more specific character or application, are used for the smaller divisions, Subrangs, Grads, and Subgrads.

Inasmuch as few if any of the rock names at present in use, even the broadest, cover the wide mineralogical concepts involved in our proposed Orders, and as it will also be well to make the names of these broad groups quite distinctive, we have adopted as the source of the roots for Orders the names of countries. We have endeavored to select in each case the name of a country where the respective Order is found in especial abundance or is most typically represented, or which is historically connected with the Order. This is, of course, not possible in every case, as some of the most abundant Orders are represented in several countries. In such cases we have endeavored to apportion the ordinal roots equitably among the petrographically prominent nations.

*b*) The selection should be based on rocks of which good analyses exist. This is obviously just, since a poor analysis is of little use, and is often of positive harm, to the science and to any system of classification, and furthermore it will frequently happen that a name based on such will prove eventually to have been misapplied.

*c*) A locality root already in use should be employed if possible.

*d*) As far as is consistent with the preceding principles, the laws of priority will hold good, as usually recognized and as formulated in Dana's *System of Mineralogy.*

*e*) In selecting a new root from several possible localities, the one should be chosen which is best known, has been best described, or which furnishes the most typical material.

*f*) The roots should be short, if possible not more than two syllables, and euphonious.

*g*) The name of a locality where the mode is normative is to be employed if possible.

*h*) As far as possible localities whose rocks occur near the classificatory borders of a given group are to be avoided.

*Intermediate magmatic names.*—A rock, whose composition is such that its magma occurs so near the border line of any division of the system as to be considered a transition magma, receives a compound magma name, made by uniting the names of the two divisions concerned, and connecting them with a hyphen. The name of the division in which the rock occurs is to be preceded by that of the neighboring division.

NAMES.—As the Classes are few in number the strictly mnemonic method of root-formation is applicable to them, and we have accordingly named them on the basis of the relative amounts of the standard salic and femic minerals present, these being indicated by the syllables *sal* and *fem*, as already explained. The relative amounts are shown by the prefixes *per-* and *do-*, which stand respectively for *extremely abundant* and *dominant*. The names for the five classes are as follows :

1. Persalane: Extremely salic—$\frac{\text{Sal}}{\text{Fem}} > \frac{7}{1}$.
2. Dosalane: Dominantly salic—$\frac{\text{Sal}}{\text{Fem}} < \frac{7}{1} > \frac{5}{3}$.
3. Salfemane: Equally salic and femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{5}{3} > \frac{3}{5}$.
4. Dofemane: Dominantly femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{3}{5} > \frac{1}{7}$.
5. Perfemane: Extremely femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{1}{7}$.

For other magma units names derived from geographical localities have been used, as already explained. Those suggested by us apply to the more important divisions of the system, and to those based on the best established data, derived from the collection of several thousand analyses already referred to, and from older analyses where available. There are numerous divisions for which we have not sufficient data to warrant our suggesting names at this time. Owing to the large number of names selected, they are presented in tabulated form, in such manner that they can be understood without difficulty.

A list of all new words proposed by us, with their definitions, will be found in the Glossary at the end of this volume.

## ROCK NAMES.

As just explained, the names to be applied to the systematic divisions, or magma units, are formed from names of geographical localities modified by a series of terminations, and designate rocks so far as their chemical composition and standard mineral composition are concerned, but do not indicate their actual mineral composition or their texture. The methods of expressing these latter characters in the systematic nomenclature remain to be stated. As already said, each is treated independently of the other. We take up first the expression of the actual mineral composition.

ACTUAL MINERAL COMPOSITION.—A nomenclature that will express the mode of a rock must indicate the kinds of minerals present and their quantity. The question then arises: How far is it necessary to modify, or qualify, the magmatic names in order to accomplish this, and further: What exactness is desirable in expressing the quantity of the actual minerals present?

When the name of the magma unit to which a rock belongs is given, there is implied in it the standard mineral composition, or *norm*, and in order to describe the actual mineral composition, or *mode*, of the rock it is only necessary to state the extent to which this differs from the norm.

And since quantitative distinctions within a petrographical unit of the smallest magmatic division established by this system would further subdivide these units, it does not appear desirable in the present state of petrographical science to carry such subdivision to any considerable extent, however desirable it may become in the future.

If the mode be *normative*, that is, if there be complete or almost complete accord between the standard mineral composition and the actual, there is obviously no need of mentioning details of the actual mineral composition, since this is fully expressed by the norm. To indicate this mode it is only necessary to use the word *normative*, before the magmatic name and connected with a hyphen.

As has been already remarked, though all the various possible combinations of the feldspar molecules are regarded as standard, yet it will often be found needful to indicate the special feldspars actually crystallized. In this case, since the albite most often crystallizes with the anorthite molecule, forming a soda-lime plagioclase, and since the character of this will condition that of the alkali-feldspar, it will in general only be necessary to name the soda-lime plagioclase which is present.

If, however, it is desirable to indicate the presence of microline or anorthoclase, this can also be done.

To express the extent to which the mode of a rock differs from the norm it is necessary to state the kinds of minerals which are different as well as the amount to which they have been developed.

It is proposed to use the names of the minerals in question as adjective qualifiers of the magmatic name, as has been the custom with such names as mica-diorite, and to express their quantitative relations by means of prefixes or suffixes, or by the order of their arrangement when several mineral names are employed.

Owing to the interdependence of the minerals in any rock on each other and on the chemical composition of the magma, it is evident that, given the norm of a rock, which is involved in its magma name, it is only necessary to state the presence and amount of certain minerals developed, which are not in accord with the norm, in order to determine the modifications of the standard minerals consequent upon the development of these particular ones.

And since such modifications take place in all degrees, from the slightest possible change to the greatest possible, it is necessary to recognize in a systematic manner differences of degree. Those already suggested in the chapter on classification with respect to actual mineral classification are two: (1) modifications of the norm, which are so slight as not to interfere with the classification of the rock directly from the mode; and (2) modifications of the norm so considerable that the rock cannot be classified directly from the mode without readjustment of the molecules in accordance with the method of calculation for obtaining the norm.

In other words, we may distinguish (1) variations among the actual minerals which fall within the limits possible in rocks with normative modes, and (2) those variations among the minerals which cause the rock to possess an abnormative mode.

1. Minerals of the first kind may be termed *varietal* minerals.

They may be defined as minerals whose presence serves to characterize and distinguish different rocks of one magma unit, but whose amount is so small that they do not affect the character of the mode as normative or abnormative. Varietal minerals include: standard minerals whose presence is not indicated by the general expression of the norm, that is, the magmatic name, though an exact statement of the norm would recognize their presence; or they may include any of the non-standard minerals. For example: small amounts of quartz or feldspathoid in rocks of Order 5, in Classes I, II, III; or small amounts of hornblende and biotite, etc.

It is proposed to express in the nomenclature the presence of varietal minerals in the rock by adding to the name of the mineral the suffix *-ic*. When it is necessary to use several varietal qualifiers at one time the mineral names are to be connected by hyphens and the suffix applied to the last, as hornblende-biotitic alsbachose.

2. Minerals of the second kind, whose presence and amounts are such as to produce abnormative modes are called *critical* minerals, as already mentioned. They are for the most part alferric, but may be salic or femic, according to the mode of the rock.

It is proposed to express the presence of a critical mineral in a rock by using the name of the mineral without modification, compounding it with the magmatic name by means of a hyphen.

In case there are several critical minerals present, their names are to be used in such order that the most abundant stands nearest to the magmatic name, and the least abundant the farthest from it.

It may become desirable when the number of mineral names is considerable to abbreviate and compound them in the manner suggested by Chamberlin,[1] and Jevons.[2]

It is to be remarked that it will not always be necessary to state the exact character or species of the critical mineral. It

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[1] *Geology of Wisconsin*, Vol. I. pp. 30–40. Madison, 1883.

[2] *Geol. Mag.*, Vol. VIII, p. 304, 1901.

will often merely be necessary to mention the mineral group, whether augite, hornblende, mica, garnet, etc. This is because experience shows that in a magma of a given character the augite or hornblende formed will in general be of a more or less constant character. Thus in highly calcic magmas the augite will in general be of one kind, in sodic magmas of another, and in magnesic magmas of another.

The critical minerals, especially the alferric, may be developed within wide limits, which in the more femic Classes may be illustrated by three rocks of the dosodic Subrang of the alkalicalcic Rang of the Order portugare, of the salfemane Class. In this we find the hornblendite of Gran, which consists entirely of an alkalic hornblende, with no visible salic or femic minerals. Here also belongs the olivine-gabbro-diabase of the same locality, in which much of the feldspar has actually crystallized as such, and in which the hornblende consequently is less alkalic, and augite is present. We also find here a nephelite-basanite of Colfax county, New Mexico, in which the actual composition corresponds quite closely with the norm. The chemical analyses of these three rocks show their chemical likeness.

In the first case all the possible alferric mineral has been

| No. | 1. | 2. | 3. | No. | 1. | 2. | 3. |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 37.90 | 43.65 | 42.35 | $P_2O_5$ | tr | tr | .99 |
| $Al_2O_3$ | 13.17 | 11.48 | 12.29 | $SO_3$ | ..... | ..... | .05 |
| $Fe_2O_3$ | 8.83 | 6.32 | 3.89 | S | ..... | ..... | tr |
| FeO | 8.37 | 8.00 | 7.05 | $Cr_2O_3$ | ..... | ..... | .10 |
| MgO | 9.50 | 7.92 | 13.09 | $V_2O_3$ | ..... | ..... | .04 |
| CaO | 10.75 | 14.00 | 12.49 | NiO | ..... | ..... | .03 |
| $Na_2O$ | 2.35 | 2.28 | 2.74 | MnO | ..... | ..... | .21 |
| $K_2O$ | 2.12 | 1.51 | 1.04 | BaO | ..... | ..... | .10 |
| $H_2O+$ | 1.40 | 1.00 | 1.50 | SrO | ..... | ..... | .09 |
| $H_2O-$ | ..... |  | .32 | $Li_2O$ | ..... | ..... | tr |
| $CO_2$ | ..... | tr | ..... |  |  |  |  |
| $TiO_2$ | 5.30 | 4.00 | 1.82 |  | 99.69 | 100.16 | 100.19 |

No. 1. Hornblendite, Brandberget, Gran, Norway. V. Schmelck, anal.; BRÖGGER, *Erupt. Gest. Kryst. Geb.*, Vol. III (1899), p. 93.

No. 2. Olivine-gabbro-diabase, Brandberget, Gran, Norway. V. Schmelck, anal.; BRÖGGER, *Quart. Jour. Geol. Soc.*, Vol. L (1894), p. 19.

No. 3. Nephelite-basanite, Ciruella, Colfax Co., N. M. W. F. Hillebrand, anal.; *Bull. 168, U. S. G. S.* (1900), p. 171.

formed, as hornblende, in the second case only a part, approximately half, chiefly as augite, while in the last very little such modification of the norm has taken place.

It is possible to devise a method of expressing in the nomenclature relative amounts of critical minerals for a comparatively simple case such as the one just given. But the problem is more complicated when several of these minerals, as hornblende, augite, and mica, are present at the same time, which frequently happens. The development of one modifies the maximum that may be attained by another, so that the expression of the relative degrees of development of each is a function of the others, and an exact expression in the nomenclature becomes extremely difficult, and is perhaps impracticable.

It will often be found useful to be able to indicate the presence of certain minerals in rock groups, when the relative amount which determines the Order, or lesser division, is not known or needful for the purpose in view. Thus we may want to speak of the persalanes or the dosalanes which carry quartz or nephelite, without specifying the relative amounts of these, *i. e.*, without making use of the ordinal divisions. In these cases it is proposed that the name of the mineral be given followed by the word *-bearing*. So the cases just mentioned would be quartz-bearing or nephelite-bearing persalane and dosalane respectively. Such names indicate only that the rocks belong to these Classes and carry quartz or nephelite, with no implication of their other characters.

### TEXTURE.

As already explained, the texture of a rock is to be expressed in the nomenclature by a qualifying term applied to the name of the magmatic unit, and connected with it by a hyphen.

There are now in use terms expressing some of the commonest and most characteristic textural features of igneous rocks. It is proposed to use these in their present form, or to modify them by abbreviation in some cases with the addition of syllables indicating the degree of granularity. The syllable *-o* is added to indicate that the texture is recognizable megascopically ; *-i* is added when it is microscopic. For example:

*Granitic* = xenomorphic and hypautomorphic granular ; *grano* = megascopically granitic, megagranitic ; *grani* = microscopically granitic, microgranitic.

*Trachytic* = panautomorphic with tabular feldspars ; *tracho* = megascopically trachytic, megatrachytic ; *trachi* = microscopically trachytic, microtrachytic.

*Graphic* = pegmatitic = granophyre in the Rosenbusch sense ; *grapho* = megagraphic ; *graphi* = micrographic.

*Poikilitic ; poikilo* = megapoikilitic ; *poikili* = micropoikilitic.

*Ophitic ; ophito* = megophitic ; *ophiti* = microphitic.

*Felsitic* = aphanitic ; *felso* = megafelsitic ; *felsi* = microfelsitic, microscopically homogeneous, but not isotropic glass.

*Vitreous ; vitro* = megascopically vitreous ; *vitri* = microscopically vitreous.

*Spherulitic ; sphero* = megaspherulitic ; *spheri* = microspherulitic.

*Porphyritic ; phyro* = megaporphyritic ; *phyri* = microporphyritic, that is, the phenocrysts are not megascopically notable, or are quite insignificant.

With the term *phyr* may be combined one indicating the texture of the groundmass as follows:

*Porphyritic granitic ; granophyro* = megagranitic, megaporphyritic ; *graniphyro* = microgranitic, megaporphyritic (granophyric in the Vogelsang sense) ; *graniphyri* = microgranitic, microporphyritic.

*Porphyritic graphic ; graphophyro* = megagraphic, megaporphyritic ; *graphiphyro* = micrographic, megaporphyritic ; *graphiphyri* = micrographic, microporphyritic.

*Porphyritic felsitic ; felsophyro* = megascopically felsitic and porphyritic ; *felsophyri* = megafelsitic, microporphyritic ; *felsiphyri* = microscopically felsitic and porphyritic.

*Porphyritic vitreous ; vitrophyro, vitrophyri, vitriphyro, vitriphyri.*

*Porphyritic poikilitic ; poikilophyro, poikiliphyro,* etc.

*Porphyritic ophitic ; ophitophyro, ophitiphyro,* etc.

*Aphyro* = megascopically non-porphyritic, or *aphyric.*

*Aphyri* = microscopically non-porphyritic, or *aphyric.*

*Salphyro* = megascopically porphyritic with salic phenocrysts, *salphyric.*

*Femphyro* = megascopically porphyritic with femic phenocrysts, *femphyric.*

*Alferphyro* = megascopically porphyritic with alferric phenocrysts, *alferphyric.*

*Salfemphyric, alfersalphyric, alferfemphyric* etc.

From the foregoing statement we may summarize the method of formulating the nomenclature here proposed as follows:

1. The *magmatic name*, of whatever division is to be indicated, which is formed by the use of the locality root and appropriate termination, stands as the basis of nomenclature, and is the substantive part of the terminology. This is because the fundamental character of igneous rocks is the chemical composition of the magma, which persists whatever be the mineral development or the texture determined by conditions obtaining during solidification.

2. According to the information at hand, or to be conveyed, the *magmatic name* must be selected which represents the Class, Order, or other division to which the rock belongs. And this name may be qualified by mineral and textural adjectives. Thus it is possible to indicate the Class of a rock, when first observed in the field, and to describe its chararteristic mineral components, and its texture. If the relative proportions of its dominant minerals, salic or femic, can be readily determined, the magmatic name for the *Order* can be used. Subsequently more specific magmatic names can be given to it. In each of these cases the critical mineral and the texture can be indicated by the same qualifying terms, or more precise ones if needed.

In this respect this system possesses a distinct advantage over former ones, in which no attempt has been made to indicate in the nomenclature the degree of exactness with which the rock is known or is to be described.

3. To indicate the actual mineral character of a rock when its *magmatic name* is given it is only necessary to express either the fact that it is standard or the departure from the norm by mentioning those *critical* minerals whose presence induces changes in the norm, or those *varietal* minerals which may be present. When such exactness is desired:

*a*) If the rock possesses a *normative mode* the actual mineral composition is expressed by using the word normative before the magmatic name.

*b*) If the rock does not possess a normative mode and it is desired to indicate the *critical* minerals present, it is proposed that such mineral qualifiers be used in some cases without introducing quantitative modifications. These mineral qualifiers may be used as full names attached to the magmatic name by a hyphen, as is the present practice, or they may be abbreviated and compounded.

*c*) It is suggested that the presence of small amounts of important minerals be indicated by adding the suffix-*ic* to the mineral name.

4. The texture is to be indicated by adjectives expressing the fabric, the crystallinity, and the granularity, and may be the terms in common use, those suggested above, or abbreviations of these.

5. Either mineral or textural qualifiers may be placed next to the magmatic name according to the emphasis to be given them, it being generally understood that the term nearest the magmatic name carries the strongest emphasis; the magmatic name coming last. The same rule is to be applied to the arrangement of several mineral qualifiers, that nearest the magmatic name is to be considered the most important.

*Examples.*—To illustrate the methods proposed, the following examples may be given, especial stress being laid on the possibility of expressing the exact amount of knowledge which is at hand or is to be conveyed

1. The typical monzonite of Brögger, from Monzoni—an evenly granular, phaneric rock, composed, as seen in the field, of dominant feldspars, with only traces of quartz, considerable pyroxene, hornblende, and less biotite, with insignificant amounts of magnetite and apatite.

From the analysis by V. Schmelck[1] the following norm is calculated :

| | | | |
|---|---|---|---|
| Orthoclase | 26.1 | | 68.1 |
| Albite | 26.2 | | |
| Anorthite | 15.8 | | |
| Diopside | 18.4 | 24.5 | 31.9 |
| Hypersthene | 3.3 | | |
| Olivine | 2.8 | | |
| Magnetite | 5.3 | 6.1 | |
| Ilmenite | 0.8 | | |
| Apatite | 1.3 | 1.3 | |
| | | | 100.0 |

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[1] W. C. Brögger, *Eruptivgest. Kristianiageb.* Vol. II, p. 24, 1895.

The rock belongs, therefore, to Class II, the *dosalanes*, with salic minerals dominant over femic, and this is evident even in the field.

Since, among the dominant salic minerals, neither quartz nor feldspathoids (lenads) are present, it belongs to the fifth Order, and is consequently, *germanare*. This, likewise, can be determined from the megascopic examination.

On referring to the analysis it is seen that the alkalies are to lime in normative anorthite as the ratio $0.097:0.057=1.70$. The rock, therefore, belongs to the second Rang, the domalkalic, to which we have given the name of *monzonase*. This, and the following points, could not be determined in the field.

As $K_2O':Na_2O' :: 0.047:0.050$, the two are in nearly equal amount, and the Subrang is thus the third, sodipotassic, which we have called *monzonose*.

We have thus characterized the rock completely, as far as the dominant minerals are concerned. Taking up the subordinate ones, we see from the norm that the pyroxenes and olivine are together dominant over the non-silicates, magnetite and ilmenite, the apatite being in negligible amount. The Grad is therefore the second, and this might be called *monzonate*.

Coming to Subgrad, we have to deal with the chemical character of the femic minerals. This is $(Mg, Fe)O:CaO' :: 0.160:0.094=1.702$. The Subgrad is the second, domiric, and this might be named *monzonote*.

Taking up next the mode and texture, it has been seen that the mode is normative as far as the salic minerals are concerned, but that hornblende, with a little biotite, largely replaces the normative femic minerals. Hornblende is therefore the *critical* mineral and biotite the *varietal*. The texture is simply a normal granitic one and rather coarse, for which we use the term *grano*.

In the field, then, the rock would be referred to either its Class, as *biotitic hornblende-grano-dosalane*, or its Order, as *biotitic hornblende-germanare*, or as a *grano-hornblende-germanare*, if we wished to disregard the small amount of biotite and emphasize the hornblende content.

Further study with the microscope and in the laboratory would allow us to speak of the rock as *grano-hornblende-monzonase*, or *biotitic hornblende-grano-monzonose*, according to what information we wished to convey.

The augite-latite of the Dardanelle Flow, in Tuolumne county, California,[1] which belongs to the same Subrang, would be spoken of as *normative phyro-monzonose*, since the augite is almost wholly diopside. Since, however, in the norm of this rock pyroxene and magnetite are present in equal amounts, it would belong to the third Grad, which might be called *dardanellate*.

Similarly, confining ourselves to the same Subrang, the olivine-trachyte of the Arso, in Ischia, would be *olivinic-phyro-monzonose*, the gauteite of Hibsch[2], a *hornblende-trachiphyro-monzonose*,and the mica-basalt of Santa Maria Basin, Arizona,[3] a *felsophyro-biotite-monzonose*. A glassy facies of any of these, with hornblende phenocrysts, for example, would be *hornblende-vitro-monzonose*. A pure glass of this composition would be simply a *vitro-monzonose*, or *aphyrovitro-monzonose;* if microlitic it would be a *phyrivitro-monzonose*.

To take another example, the normal, lithoidal, micro-spherulitic and porphyritic rhyolite of the Yellowstone National Park is *spheriphyro-alaskose*, which is a very concise expression for a rock that is microscopically spherulitic, megascopically porphyritic, having the chemical composition of a rock whose norm consists of extreme salic minerals, of which quartz and feldspar are nearly equal, the feldspars extremely alkalic, and soda and potash in nearly equal proportions.

An example of intermediate rock is to be found in the granite of Butte, Mont., whose composition is discussed at length in connection with the calculation of norm and mode. This rock belongs near the border line between Classes I and II, and the rock from Walkerville Station, Butte, has $\frac{\text{sal}}{\text{fem}} = 7.14$. It is a

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[1] F. L. Ransome, *A. J. S.*, Vol. V, p. 363, 1898.

[2] J. E. Hibsch, *T. M. P. M.*, Vol. XVII, p. 84, 1897.

[3] *Bull. 148 U. S. G. S.*, p. 187 (B, C, D), 1897.

persalane near dosalane, and may be called dosalane-persalane, which contracts to do-persalane.

The Order is quardofelic,

$$\frac{F}{Q} = 3.4, < \frac{7}{1} > \frac{5}{3};$$

it is britannare (Class I) near austrare (Class II), or austrare-britannare. The Rang is alcalicalcic,

$$\frac{K_2O' + Na_2O'}{CaO'} = 1.38, < \frac{5}{3} > \frac{3}{5};$$

it is coloradase (Class I) near tonalase (Class II), or tonalase-coloradase. The Subrang is sodipotassic,

$$\frac{K_2O'}{Na_2O'} = 1, < \frac{5}{3} > \frac{3}{5};$$

it is amiatose (Class I) near harzose (Class II) or harzose-amiatose.

TYPE AND HABIT.—It is clearly obvious that if great precision or completeness be desired, so that both mineralogical and textural qualifiers are used, the polynomial name resulting will be of considerable length, comparable to such present names as quartz-hornblende-biotite-diorite-porphyry. This will probably not be as great a practical difficulty or inconvenience as may appear at first sight, since after a given rock has been described and named in full in any given article, it may be referred to subsequently by its magmatic name alone, or by this in conjunction with a textural or modal term, according to circumstances.

However, since the same or similar assemblages of modal and textural characters are found in many localities it will be as well to be able to express these concisely. This is, after all, what is accomplished by many of the names in the present systems of nomenclature, although it has not been done systematically. Thus the names granite, rhyolite, tinguaite, laurvikite, etc., convey primarily an idea of the qualitative mineral composition and the texture of the respective rocks, with a very rough one of the magmatic character.

It is to be noted that there are two degrees of similarity among rocks which can be easily recognized and made use of. One is almost complete *identity*, the other a *general resemblance* which suggests identity.

*Type.*—For the first of these, *identity* or almost complete identity, we propose the use of the term *type*. Rocks of the same type are identical in norm, mode, and texture, or almost completely so. They are of the same grain, have the same fabric, the same actual mineral composition, and are so much alike that they may be mistaken for one another or might have been parts of one rock body. Many examples of such close similarity are familiar to all petrographers.

The particular modal and textural features which characterize rocks of a given type are to be expressed by a single adjective word, composed of a root derived from a geographical locality in which a rock of the type occurs, but not already employed to designate a magmatic unit, and the termination *-al.*

*Habit.*—In order to express the fact that one rock resembles in general appearance another well-known rock by exhibiting some of its characteristic features without being identical in composition or mode we propose to use the term *habit*, formerly in constant requisition among petrographers. The features of a rock characterizing its habit may be both textural and mineral. For example: one rock may be porphyritic, with a dark-colored, aphanitic groundmass, and the phenocrysts rhombic feldspars. Another rock may have these features, but belong to a chemically different magma. The two may be said to have the same habit. And the second may be sufficiently described by giving its proper magmatic name qualified by an adjective indicating the habit of the first rock.

To accomplish this we propose that the habit of a rock be expressed by a word formed similarly to one expressing type but with the termination *-oid.* The root of the word is to be taken from some geographical locality. It may be the same as one used for a type, since a common type rock may be one whose habit will often be used in describing another, less common, rock.

Thus a particular form of rock belonging to the Order russare, of the persalanes, may constitute the *tingual type*, with definite norm, mode, and texture; while a somewhat similarly appearing rock belonging to the Order norgare, of the dosalane Class may possess a *tinguoid habit.*

The habital qualifier may be applied to a magmatic name of any systematic division, since it does not specify the composition of a rock. Thus we may describe a rock as a tinguoid dosalane, or a tinguoid norgare, a tinguoid laurdalase, etc. There may be tinguoid persalanes and salfemanes.

It is obvious that, with the use of types and habits, the nomenclature will tend to become binomial, and hence much more easy of application than in the present systems, or in the full one proposed here. It will, however, differ radically from the binomial nomenclature in use in the organic sciences, since the habital qualifier will not correspond to the specific terms of these, applicable only to the generic name, but will be applicable to any division of the classification from Class to Subgrad.

### ROCK NAMES FOR GENERAL FIELD USE.

It is obvious that a considerable part of the system of classification and nomenclature here proposed can only be applied upon microscopical or chemical investigation. This is equally true of a large part of that in present use. There are many distinctions based on characters that cannot be observed with the unaided eye, such as differences among the plagioclase feldspars, and the mineral composition of aphanitic rocks.

It is also clear that the system demands a more detailed knowledge of rocks than many geologists, mining engineers, and others interested in geology, may care to acquire. This is a natural consequence of the advance in petrological science, which requires a corresponding advance in specialization and in petrographical classification and nomenclature.

For these reasons, which might be elaborated at considerable length, we are convinced of the need of general petrographical terms which will be serviceable in the field work of the petrologist, and which will be of use to the general geologist and to those who may not be able to carry on microscopical and chemical investigation.

Such general terms should be based on megascopic characters of the rocks and should be limited to such characters. Their application should be purely objective and everything of a subjective nature should be eliminated. It follows from this that such terms cannot be correlated with those used in the systematic nomenclature based on chemical and microscopical properties. They must be understood to have a totally different scope, and to indicate no more than the general megascopic characters with which they are connoted.

The attitude of the person using such terms is the same as that of geologists who studied rocks before the introduction of the microscope, and most of the distinctive features exhibited megascopically by igneous rocks were well known and appropriately named by the early geologists, and most of the terms used by them are in use at the present time, though their application has been variously modified by repeated redefinition.

We recommend that those terms which are needed for general field purposes, and are to be based on purely megascopic characters, be selected from the terms originally proposed by the founders of geology, and be given their original significance so far as possible, with only such modifications as a somewhat more systematic treatment of the matter may suggest.

When all igneous rocks are considered with reference to their megascopic characters their most generally recognizable features appear to be their *texture* and *color*, and in some cases, and to various degrees, their *mineral constituents*.

If we attempt to group them according to texture we find them falling into three large divisions:

1. Those whose mineral components can be seen with the unaided eye.

2. Those whose mineral components cannot all be seen with the unaided eye, and that are composed of a greater or less amount of lithoidal material not resolvable into its component parts.

3. Those with vitreous luster in the whole or a part of the mass.

The first have been called by Hauy phanerogène, and may be termed *phanerites*.

The second have been called by d'Aubuisson (1819) *aphanites*, a name which cannot be improved upon.

The third have been long known as volcanic glasses—*obsidian*, *pitchstone*, etc.

All phanerites, whether igneous or metamorphic, massive or schistose, were at an earlier time called *granite*. But at the beginning of the last century a number of kinds of phanerocrystalline (phaneric) rocks were recognized, the distinctions being based upon the minerals that could be identified megascopically. These minerals are: quartz, feldspar, leucite, nephelite, mica, hornblende, augite, the iron ores, etc. It is to be remembered that there were no specific distinctions among the feldspars. It is equally true at this day that no specific distinctions can be made with the unaided eye among the lime-soda-feldspars, and that albite, oligoclase, andesine, and labradorite cannot be identified as such without optical or chemical tests. It follows from this that phaneric rocks cannot be classed by purely megascopical means as having alkali-feldspars, or more calcic feldspars. We must not attempt to subdivide these rocks on the basis of characters not recognizable megascopically and must content ourselves with employing mineral groups, such as feldspar, mica, amphibole (hornblende), pyroxene, etc., as bases for their field designation.

For these reasons we suggest the following use of familiar terms when rocks are to be named on a purely megascopical basis.

I. PHANERITES—phanerocrystalline (phaneric) rocks.

1. *Granite*—all granular igneous rock composed of dominant quartz and feldspar, of any kind, with mica, hornblende, or other minerals in subordinate amount. This is the granite of Werner, von Leonhard, and other early geologists, and will include what is now termed granite, granodiorite, tonalite, and most quartz-

diorites. It will embrace all light-colored, granular rocks with dominant feldspar and a noticeable amount of quartz. It will include the quartz- (hornblende) -syenites of earlier geologists.

2. *Syenite*—all granular igneous rocks composed of dominant feldspars, of any kind, with subordinate amounts of mica, hornblende, pyroxene, or other minerals, and without noticeable amount of quartz. This is the syenite of Werner, von Leonhard, and others, with slight modification, and will include modern syenite, anorthosite, and the more feldspathic monzonites, diorites, and gabbros. If it is desirable to distinguish the plagioclase rocks when recognizable, such as the coarse-grained anorthosites, they may be called plagioclase-syenites, or anorthosites.

3. *Diorite*—all granular igneous rocks with dominant hornblende and subordinate feldspar of any kind. This is the diorite of d'Aubuisson (1819) as defined by von Leonhard (1823). It will include the less feldspathic diorites and hornblende-gabbros.

4. *Gabbro*—all granular igneous rocks with dominant pyroxene and subordinate feldspar of any kind, with or without hornblende and mica. Essentially the gabbro of von Leonhard. Since it is not possible to identify pyroxene as distinct from hornblende in many cases, megascopically, it will probably happen that all of those rocks which can be clearly seen to contain dominant hornblende will be called diorite, and all doubtful ones will be grouped with the distinctly pyroxenic gabbros. These rocks will include the less feldspathic gabbros and norites, and some diorites.

5. *Peridotite*, *pyroxenite*, and *hornblendite*—all granular igneous rocks composed almost completely of olivine, pyroxene, or hornblende, in variable proportions, with little or no feldspar. These names are to be applied as at present.

Other names in common use, which can be applied without confusion upon the basis of purely megascopical determination, may be used.

II. APHANITES—lithoidal, aphanitic rocks. These may be non-porphyritic or porphyritic, the aphanitic character being confined to the groundmass.

A. *Non-porphyritic forms*, having no recognizable mineral constituents, must be subdivided, if at all, upon the basis of color, luster, or other physical properties. The early distinctions were in reality on a basis of color, and were two:

1. *Felsite* (Gerhard, 1814), Phonolite (Klaproth, 1801), Petrosilex of the French geologists. *Felsite* includes all aphanitic igneous rocks that are non-porphyritic and are light-colored, in various tones, and with various lusters other than vitreous. They include lithoidite (von Richthoven, 1860), or lithoidal rhyolite, non-porphyritic trachite, and phonolite, and the lighter colored non-porphyritic andesites, latites, etc.

2. *Basalt*—all dark-colored, aphanitic, igneous rocks without phenocrysts. This will include the dark-colored andesites, non-porphyritic basalts, diabases, and other lavas known by a number of names, which before the classic studies of Zirkel were grouped togther as basalt.

B. *Porphyry*—porphyritic forms may all be embraced within the general term of *porphyry*. They may be separated on a basis of color to correspond to the divisions above mentioned into two groups.

1. *Leucophyre* (Gümbel, 1874) and
2. *Melaphyre* (Brongniart, 1813).

Gümbel applied the term leucophyre to certain altered diabases of light color, which would not be included within the group here proposed, but the term was applied to altered rocks and has never been in general use, and may advantageously be redefined.

*Leucophyres* would include all porphyritic, aphanitic, igneous rocks, with light-colored groundmass, and with phenocrysts of any kind.

*Melaphyres* would include all porphyritic, aphanitic igneous rocks with dark-colored groundmass, and with phenocrysts of any kind.

According to the kinds of phenocrysts which may be identified megascopically these rocks may be named without reference to the color of the groundmass as:

*Quartz-porphyry* or *quartzophyre.*

*Feldspar-porphyry* or *feldsparphyre*, but not felsophyre, since this name is in common use for a porphyry with felsitic groundmass.

*Hornblende-porphyry* or *hornblendophyre.*

*Mica-porphyry* or *micaphyre.*

*Augite porphyry* or *augitophyre* (von Buch, 1824).

*Olivine-porphyry* or *olivinophyre* (Vogelsang, 1872).

If it is intended to indicate the color of the groundmass as light or dark, we may use the terms:

*Quartz-leucophyre* or *quartz-melaphyre.*

*Feldspar-leucophyre* or *feldspar-melaphyre.*

*Hornblende-leucophyre* or *hornblende-melaphyre.*

It is to be remembered that these terms leucophyre and melaphyre imply nothing as to the composition of the groundmass. They strictly indicate nothing but its color.

III. THE GLASSES—glassy rocks have been classified on a basis of luster and texture as follows:

1. *Obsidian*—vitreous rock of any color, usually black, often red, less often brown and greenish.

2. *Pitchstone*—resinous and less lustrous than obsidian, and consequently lighter colored.

3. *Perlite*—glassy rock with perlitic texture produced by small spheroidal fractures.

4. *Pumice*—highly vesicular glass, usually white or very light-colored.

Each of these varieties may be non-porphyritic or porphyritic. The latter may be called

*Vitrophyre* (Vogelsang, 1867) and may be qualified by mineral terms indicating the character of the prominent phenocrysts yielding *quartz-vitrophyre*, *feldspar-vitrophyre*, etc. They may also be called porphyritic obsidian, pitchstone, perlite, or pumice.

# PART III.

## METHODS OF CALCULATION.

In order to obtain concordant results in all cases in the determination of the kinds and amounts of standard minerals that correspond to a magma of any given chemical composition, a uniform method of calculation is necessary. This calculation may be made either from the chemical analysis of the rock or from the quantitative estimate of the minerals actually present in it.

The calculation of *standard minerals* belonging to the salic and femic groups, rather than that of the actual minerals which may be present in the rock, is warranted not only by the fact of the variable possibilities of crystallization in one magma, but because of the difficulty of determining the quantity and chemical character of the minerals actually present in many rocks. It is further warranted because of the impossibility of determining the minerals in a great number of rocks in which they are too small, and because of the incomplete crystallization of all more or less glassy rocks.

The variability in the development and chemical composition of the *alferric minerals* justifies us in treating them as combinations by readjustment of salic and femic molecules. Their chemico-mineralogical relations and the method of calculating their proportions will be stated later on.

The method of calculation adopted is based upon a number of commonly observed chemico-mineralogical relations that obtain in the rock-making minerals, which may be stated as follows:

CHEMICAL RELATIONS AMONG SALIC MINERALS.—1. The constant relation between the molecules of $Al_2O_3$ and $K_2O$ and $Na_2O$ in orthoclase and albite, leucite and nephelite ($Al_2O_3 : K_2O + Na_2O :: 1 : 1$).

2. The somewhat similar relation between these constituents

in the sodalites, where the soda is slightly in excess. The ratio in sodalite is $Al_2O_3 + \frac{1}{3}Cl_2 : Na_2O + \frac{1}{3}Na_2O :: 1 : 1$; in noselite it is $Al_2O_3 + \frac{1}{2}SO_3 : Na_2O + \frac{1}{2}Na_2O :: 1 : 1$.

3. The constant relation between $Al_2O_3$ and CaO in the anorthite molecule ( $Al_2O_3 : CaO :: 1 : 1$).

4. The development of corundum under favorable conditions in rocks with excess of $Al_2O_3$ over $K_2O$, $Na_2O$, and CaO.

5. The relation between the development of alkali-feldspar (polysilicates) and of feldspathoids (meta- and ortho-silicates) and the available silica in the magma, so that free silica (quartz) does not crystallize together with leucite and nephelite.

6. The stronger affinity of $Al_2O_3$ for $K_2O$ than for $Na_2O$, and its stronger affinity for both of these than for CaO, $Al_2O_3$ forming alkali-feldspars and feldspathoids (lenads) in preference to anorthite.

7. The constant ratio between $ZrO_2$ and $SiO_2$ in zircon, $ZrO_2 : SiO_2 :: 1 : 1$.

CHEMICAL RELATIONS AMONG FEMIC MINERALS.— 1. The constant relation between $Fe_2O_3$ and $Na_2O$ in the acmite molecule ($Fe_2O_3 : Na_2O :: 1 : 1$).

2. The general fact that this molecule is developed in magmas when $K_2O$ and $Na_2O$ are in excess of $Al_2O_3$.

3. The constant relation between $Fe_2O_3$ and FeO in magnetite ($Fe_2O_3 : FeO :: 1 : 1$).

4. The relation between FeO and $TiO_2$ in ilmenite ($FeO : TiO_2 :: 1 : 1$).

5. The relation of $TiO_2$ and CaO in titanite and in perofskite ($TiO_2 : CaO :: 1 : 1$).

6. The development of the titano-silicate, titanite, in the more siliceous rocks, and of the non-siliceous perofskite in its place in the less siliceous ones.

7. The constant relation of $P_2O_5$ to CaO in apatite ($P_2O_5 : CaO :: 1 : 3.33$).

8. The relation of CaO and (Mg,Fe)O in monoclinic pyroxene, diopside ($CaO : (Mg,Fe)O :: 1 : 1$).

9. The occurrence of (Mg,Fe)O both as metasilicate or orthosilicate, in hypersthene and olivine.

10. The frequent, but not invariable, relation between (Mg,Fe)O and available silica, whereby metasilicate, hypersthene, forms instead of orthosilicate, olivine, with sufficient available silica.

11. The occasional occurrence of a sodium metasilicate molecule, $Na_2O.SiO_2$, which enters into arfvedsonite in rocks in which $K_2O$ and $Na_2O$ are in excess of $Al_2O_3$ and $Fe_2O_3$.

12. The fact that, apart from apatite, the only common non-silico-aluminous, primary rock-making minerals are magnetite and ilmenite; the iron being the only element of the important ones which in rocks can crystallize without $SiO_2$ or $Al_2O_3$.

13. Finally the common occurrence of $SiO_2$, CaO and $Na_2O$ in minerals of both the salic and femic groups, and their resulting interdependence.

CALCULATION OF THE NORM.

The method adopted by us of calculating the standard mineral composition is as follows:

1. Determine the molecular proportions of the chemical components of a rock as expressed by the complete analysis, by dividing the percentage weights of each component by its molecular weight.

2. Before undertaking the distribution of the chemical components as mineral molecules, small amounts of MnO and NiO are to be united with FeO, and of BaO and SrO with CaO; of $Cr_2O_3$ with $Fe_2O_3$, unless these unusual components occur in sufficient amounts to make their calculation as special mineral molecules desirable. These amounts are indicated in connection with examples of calculation given later.

3. Establish the fixed molecules by allotting:

*a*) to $Cr_2O_3$, if present in notable amount, FeO to satisfy the ratio $Cr_2O_3$ : FeO : : 1 : 1 for chromite;

*b*) to $TiO_2$ enough FeO to satisfy the ratio $TiO_2$ : FeO : : 1 : 1 for ilmenite. If there is excess of $TiO_2$, allot to it equal CaO for titanite or perofskite according to available silica, to

modification
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Excess of $TiO_2$ over available FeO is combined with CaO in the ratio CaO : $TiO_2$ = 1 : 1 in titanite or perofskite after the allotment of CaO to $Al_2O_3$ in anorthite, i.e. 5 a) and according to the silica available etc be determined later. If there is still an excess of $TiO_2$ it is to be calculated as rutile;

*c*) to $P_2O_5$ allot CaO to satisfy the ratio $P_2O_5 : CaO :: 1 : 3.33$ for apatite. Allot F or Cl to satisfy $CaO = 0.33P_2O_5$;

*d*) to F not used in apatite allot CaO to form fluorite, $CaO : F :: 1 : 2$;

*e*) to Cl not used in apatite allot $Na_2O$ in the ratio $Cl_2 : Na_2(O) :: 1 : 1$ for sodalite;

*f*) to $SO_3$ allot $Na_2O$ in proportion $SO_3 : Na_2O :: 1 : 1$ for noselite;

*g*) to S allot FeO in proportion $S : Fe(O) :: 2 : 1$ for pyrite;

*h*) to $CO_2$ in undecomposed rocks allot CaO in the proportion $1 : 1$ for calcite. $CO_2$ may occur in primary calcite and cancrinite. If these minerals are secondary, the $CO_2$ is to be neglected, since it is understood that analyses of decomposed rocks are not available for purposes of classification.

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allot to
$Cl + SO_3$
sufficient
$Na_2O$ to form
$NaCl + Na_2SO_4$
and include
among salic
components

Having adjusted the minor, inflexible, molecules, there remain the more important but variable silicate molecules, which form the great part of the standard mineral composition, or *norm*, of most rocks.

4. To $Al_2O_3$ are allotted all the $K_2O$ and $Na_2O$, not already disposed of, in the proportion of $Al_2O_3 : K_2O + Na_2O :: 1 : 1$ for alkali feldspathic and feldspathoid (lenad) molecules.

*a*) $K_2O$ is allotted first, because of its stronger affinity for $Al_2O_3$, in the proportion of $Al_2O_3 : K_2O :: 1 : 1$ for orthoclase or leucite molecules.

*b*) $Na_2O$ is allotted to remaining $Al_2O_3$ in proportion of $1 : 1$ for albite or nephelite molecules

5. With excess of $Al_2O_3$, ($Al_2O_3 > K_2O + Na_2O$):

*a*) to extra $Al_2O_3$ allot CaO in proportion of $Al_2O_3 : CaO :: 1 : 1$ for anorthite molecules.

*b*) If there is further excess of $Al_2O_3$ it is to be considered as corundum, $Al_2O_3$.

It it is not advisable to calculate muscovite with excess of $Al_2O_3$ instead of corundum, since it requires a readjustment of orthoclase molecules, and muscovite may not occur in the rock, the extra $Al_2O_3$ entering alferric minerals. Its calculation is considered subsequently.

6. With insufficient $Al_2O_3$, ($Al_2O_3 < K_2O + Na_2O$):

*a*) Extra $Na_2O$ is allotted to $Fe_2O_3$ in proportion $Fe_2O_3$ : $Na_2O$ : : 1 : 1 for acmite molecules.

*b*) If there is still extra $Na_2O$ it is set aside for a metasilicate molecule ($Na_2SiO_3$).

*c*) When there is an excess of $K_2O$ over $Al_2O_3$ it is treated in the same manner. It is an extremely rare occurrence.

7. In working with reliable analyses in which $Fe_2O_3$ and FeO have been correctly determined :

*a*) To $Fe_2O_3$ is allotted excess of $Na_2O$ under conditions6,*a*).

*b*) To remaining $Fe_2O_3$ is allotted available FeO in equal proportions for magnetite.

*c*) If there is any excess of $Fe_2O_3$ it is calculated as hematite.

Analyses in which all the iron has been determined in one form of oxidation, when it occurs in two, are of little value when considerable iron is present. When the amount of iron is very small the analyses may still be used as a means of classifying the rock. For this purpose all the iron, if given as ferric oxide, is to be calculated as FeO, except that necessary to be allotted to $Na_2O$ for acmite, and then used as below.

8. *a*) Extra CaO after the foregoing assignments is allotted to (Mg, Fe)O in proportion CaO : (Mg, Fe)O : : 1 : 1 for diopside molecules.

In all molecules where (Mg, Fe)O is present, MgO and FeO are to be used in the same proportions in which they are found after FeO has been allotted to the molecules previously mentioned. That is, they are to be introduced into diopside, hypersthene and olivine with the same ratio between them.

*b*) If there is still an excess of CaO it is to be set aside for calcium metasilicate ($CaSiO_3$) or subsilicate ($4CaO. 3\ SiO_2$), equivalent to wollastonite or akermanite. Such extra CaO will in most cases actually enter garnet, an alferric mineral.

9. With insufficient CaO, ($CaO < (Mg, Fe)O$):

*a*) Extra (Mg, Fe)O is to be set aside for metasilicate or orthosilicate, hypersthene or olivine, according to the amount of $SiO_2$ present.

*The allotment of $SiO_2$* to form silicates begins with the bases which occur with silica in but one proportion, and is carried on as follows:

10. To $ZrO_2$ allot $SiO_2$ in proportion of 1 : 1 for zircon.

11. To CaO and $Al_2O_3$ in anorthite is allotted equal $SiO_2$ to form $CaO.Al_2O_3.2SiO_2$.

12. To CaO and (Mg, Fe)O in diopside is allotted equal $SiO_2$ to form $CaO.(Mg, Fe)O.2SiO_2$.

13. To $Na_2O$ and $Fe_2O_3$ in acmite is allotted $SiO_2$ to form $Na_2O. Fe_2O_3.4SiO_2$.

14. To $Na_2O$ (or $K_2O$) set aside for metasilicate molecules allot $SiO_2$ to form $Na_2O.SiO_2$ or $K_2O.SiO_2$.

15. To $Na_2O$ and $Al_2O_3$ in sufficient amount to form with NaCl sodalite, or with $Na_2SO_4$ noselite, is allotted $SiO_2$ to satisfy the formulas : $3(Na_2O.Al_2O_3\ 2SiO_2).2NaCl$, sodalite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$ noselite.

The allotment of silica to bases which may form two or more silicates, ortho-, meta- or polysilicate, is controlled in part by the amount of available silica, in part by the affinities of the bases for silica as explained below, in accordance with certain commonly observed facts, as follows:

*a*) Quartz does not occur with nephelite and leucite, that is, the feldspathic molecules will be polysilicates, orthoclase and albite, if there is sufficient available silica.

*b*) Of the feldspathoids (lenads), the metasilicates—leucite and analcite—are rarer than the orthosilicates, nephelite and the sodalites. Analcite is so rare as a primary mineral that it may be omitted from the discussion, and may be regarded as composed of albite and nephelite + 2 water. Nephelite is more frequently associated with orthoclase than leucite with albite, from which it appears that potassic feldspathic molecules become polysilicate when sodic ones form orthosilicate. If there is not enough available silica to form orthoclase, leucite forms.

*c*) The method is also based on the infrequent occurrence of orthorhombic pyroxene with the feldspathoids, and the frequent occurrence of olivine with these minerals. From which may be deduced the rule that the development of metasilicate or orthosilicate of (Mg, Fe)O is controlled in most cases by the available silica after satisfying the feldspathic molecules.

*d*) Finally, the occurrence of melilite (akermanite) in rocks free from the polysilicate feldspars and the metasilicate, hypersthene, indicates that this subsilicate mineral is produced because of insufficient silica to form the lowest normal silicates commonly developed in igneous rocks.

The order of affinity of the common rock-forming oxides for silica, which is well established by the foregoing and other facts, as well as by such investigations as those of Lagorio[1] and Morozewicz,[2] is as follows, beginning with that which has most affinity, $K_2O$, $Na_2O$, CaO, MgO, FeO. The oxides $Al_2O_3$ and $Fe_2O_3$ to some extent are analogous to $SiO_2$ and play in certain respects the rôle of acidic oxides.

The validity of this order is illustrated and confirmed by the following facts: $K_2O$ and $Na_2O$ alone form polysilicates (orthoclase and albite) with the ratios $(K, Na)_2O : SiO_2 :: 1 : 6$. They also form the metasilicates (leucite, analcite and acmite) with the ratio $(K,Na)_2O : SiO_2 :: 1 : 4$. $Na_2O$ also forms the orthosilicate nephelite, as well as the minerals of the sodalite group, with the ratio $Na_2O : SiO_2 :: 1 : 2$. The corresponding potash compound, kaliophilite, is rare and not a rock-making mineral, though $K_2O$ enters into the composition of nephelite to some extent. If potash and soda are present and there is insufficient silica to form polysilicates of both, then as a general rule, $K_2O$ takes all the silica it can get to form orthoclase, or orthoclase and leucite, the soda taking the rest to form nephelite, together with albite in some cases. The occurrence of $K_2O$ in

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[1] TSCHENMAK'S *Min. Petr. Mitth.*, Vol. VIII, pp. 421 ff., 1887.

[2] *Ibid.*, Vol. XVIII, pp. 221 ff., 1899.

the micas appears at first thought to be an exception to this rule, but further consideration shows that in the muscovite molecule, $(H,K)_2O.Al_2O_3,2SiO_2$, when $H = 2K$, the $SiO_2$ is six times $K_2O$, as in orthoclase; and when $H = K$, the $SiO_2$ is four times $K_2O$, as in leucite.

CaO forms the orthosilicate anorthite with the ratio $CaO : SiO_2 :: 1 : 2$, and controls an amount of $SiO_2$ equal to itself in the wollastonite molecule. In akermanite the $CaO : SiO_2 :: 4 : 3$.

MgO and FeO can, at most, control only their own amounts of silica, in the hypersthene molecule, and also form the orthosilicate olivine, with the ratio $(Fe, Mg)O : SiO_2 :: 2 : 1$. Finally, FeO crystallizes out in non-siliceous and non-aluminous minerals, magnetite and ilmenite.

It is noteworthy that the order of affinity of these oxides for alumina is the same in relative order as that for silica. So $K_2O$ forms muscovite with an excess of alumina over potash, the analagous paragonite being rare and only found in metamorphic rocks, $Na_2O$ being slightly in excess of $Al_2O_3$ in the sodalites, CaO largely so (3:1) in garnet, and MgO and FeO having little affinity for it.

MgO and FeO can, it is true, form the non-siliceous, aluminous mineral, spinel, $RO.R_2O_3$.

In the calculation of the standard mineral composition the allotment of silica to the alternative molecules is, therefore, as follows:

16. To CaO set aside for wollastonite or akermanite is allotted tentatively $SiO_2$ to form wollastonite $(CaO.SiO_2)$.

17. To extra (Mg,Fe)O is allotted $SiO_2$ to form orthosilicate, olivine $(2(Mg,Fe)O.SiO_2)$.

18. To $Al_2O_3$ and $K_2O + Na_2O$ is allotted $SiO_2$ to make polysilicates, orthoclase and albite, $K_2O\ Al_2O_3.6\ SiO_2$ and $Na_2O.Al_2O_3.6\ SiO_2$.

*a*) If there is excess of $SiO_2$ it is added to the orthosilicate of (Mg, Fe)O to raise it to the metasilicate $(Mg,Fe)O.SiO_2$. If $SiO_2$ is insufficient to convert all the olivine into hypersthene it is distributed according to the following equations:

$$x + y = \text{molecules of (Mg,Fe)O.}$$

$$x + \frac{y}{2} = \text{available } SiO_2 .$$

modification where $x$ = hypersthene, $\frac{y}{2}$ = olivine molecules.

*b*) Further excess of $SiO_2$ is to be allotted to $TiO_2$ and CaO to form titanite. These constituents remain as perofskite when there is no excess of $SiO_2$.

*c*) Further excess of $SiO_2$ is reckoned as quartz.

19. If there is insufficient $SiO_2$ to form polysilicate feldspar out of all the $K_2O$ and $Na_2O$ with $Al_2O_3$ :

*a*) To $K_2O.Al_2O_3$ is allotted tentatively enough $SiO_2$ to form polysilicate, orthoclase ($K_2O.Al_2O_3.6SiO_2$) and the remaining $SiO_2$ is distributed between albite and nephelite molecules by means of the equations:

$$\begin{aligned} x + y &= \text{molecules of } Na_2O. \\ 6x + 2y &= \text{available } SiO_2 . \end{aligned}$$

where $x$ = albite, and $y$ = nephelite molecules.

*b*) If the available $SiO_2$ in case 15, *a*) is insufficient to form nephelite with the $Na_2O$, then enough $SiO_2$ is first allotted to the $Na_2O$ to form nephelite and the remaining $SiO_2$ is distributed between orthoclase and leucite molecules by means of the equations :

$$\begin{aligned} x + y &= \text{molecules of } K_2O. \\ 6x + 4y &= \text{available } SiO_2 . \end{aligned}$$

where $x$ = orthoclase, and $y$ = leucite molecules.

20. If there is insufficient $SiO_2$ to form leucite and nephelite with olivine it is necessary to reduce a sufficient number of molecules to form the subsilicate akermanite, $4CaO.3SiO_2$.

*a*) In case there is no wollastonite this is done after distributing $SiO_2$ tentatively to form leucite, nephelite and olivine and noting the deficit of $SiO_2$ by means of the equation:

$$y = \frac{1}{3} \text{ of the deficit of } SiO_2 .$$

$$y = \text{molecules of akermanite. } (4CaO.3SiO_2).$$

For the reduction of diopside to akermanite

$y = 2/5$ deficit of $SiO_2$

$y$ = molecules of akermanite

$3CaO\ 2SiO_2$

CaO is to be taken from diopside, and the MgO and FeO so liberated are to be calculated as olivine.

*b*) In case an excess of CaO has been set aside for wollastonite this is first converted to akermanite by means of the equations:

modification
from text 2

$y =$ the deficit of $SiO_2$.
$y =$ molecules of akermanite ($4CaO \cdot 3SiO_2$).
3

$Y =$ deficit of $SiO_2$
$Y =$ molecules of akermanite.
($3CaO\, 2SiO_2$)

*c*) If there are not sufficient molecules of wollastonite to satisfy the deficit of silica, recalculate the molecules of diopside and wollastonite so as to make olivine, diopside and akermanite by means of the formulæ.

modification

$$2x + 3y + \frac{z}{2} = \text{available } SiO_2.$$
$$x + 4y = \text{molecules of } CaO.$$
$$x + z = \text{molecules of } MgO + FeO.$$

$2x + 2y + \frac{z}{2} =$ avail $SiO_2$
$x + 3y =$ mol. CaO
$x + z =$ mol. MgO + Fe

Where $x =$ molecules of new diopside, $y =$ molecules of akermanite ($4CaO \cdot 3SiO_2$), and $z =$ molecules of olivine.

21. If there is still not enough $SiO_2$, all the CaO of the diopside and wollastonite must be calculated as akermanite, the (Mg, Fe)O being reckoned as olivine and the $K_2O$ distributed between leucite and kaliophilite by the equations:

$$x + y = \text{molecules of } K_2O.$$
$$4x + 2y = \text{available } SiO_2.$$

where $x$ is $K_2O$ in leucite and $y = K_2O$ in kaliophilite.

22. In case there is insufficient $SiO_2$ and an excess of $Al_2O_3$ and (Mg,Fe)O, which might form aluminous spinel, an alferric mineral, the excess of $Al_2O_3$ is to be calculated as corundum, and the uncombined (Mg,Fe)O is to be estimated as femic minerals, being placed with the nonsilicate, mitic, group, magnetite, ilmenite, etc.

It will be noted that as a result of the methods given above the following minerals are not found together in the *norm*, standard mineral composition, of igneous rocks; in other words, that the calculation of the former of each pair precludes that of the latter, and conversely.

With quartz there will be no nephelite, leucite or olivine.
With hypersthene there will be no nephelite or leucite.
With corundum there will be no diopside or acmite.
With anorthite there will be no acmite.
With wollastonite there will be no hypersthene or olivine.
With leucite there will be no albite.

*Percentage weights of minerals.*—Having estimated the relative number of molecules of the various mineral components, their relative masses may be obtained by multiplying each by the molecular weight. This is readily accomplished by means of tables, both for finding the molecular proportions corresponding to percentages of the chemical components given in analyses, such as those lately published by J. F. Kemp[1] and others, for finding the percentage weights of the minerals with constant composition when their molecular proportions have been calculated. The weights of minerals like olivine and pyroxene in which the component (Mg, Fe) O is variable must be calculated from the proportions of MgO and FeO present in the rock after deduction of FeO allotted to magnetite and ilmenite, the same ratio between these oxides being used for each kind of molecule containing both of them. The weights of diopside, hypersthene and olivine, in which MgO and FeO occur in varying amounts, may be computed from the sums of the simple molecules $CaSiO_3$, $MgSiO_3$, $FeSiO_3$, and $Mg_2SiO_4$, $Fe_2SiO_4$.

Tables for finding the molecular proportions of the constituent oxides, and those for the percentage weights of the standard minerals will be found at the end of this volume.

### EXAMPLES OF CALCULATIONS.

It will be useful to give some examples illustrative of the method of calculation and of the various possibilities, selected from several thousand calculated by us. To simplify

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[1] KEMP, J. F., "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, Vol. XXII, pp. 75–88.

them, the molecular weights of the minerals which have fixed molecules, as orthoclase, anorthite, magnetite, etc., are multiplied by the number of molecules of the unit oxide in each case to arrive at the percentage weight.

For general purposes very small amounts of the component oxides may be neglected. But for close work it is necessary to take into account even small percentages of $P_2O_5$, $TiO_2$, $SO_3$, etc., that is, where any one of them amounts to two units in the scale of molecular proportions; when $P_2O_5 = 0.28$, $TiO_2 = 0.16$, $SO_3 = 0.16$, $CO_2 = 0.08$, $Cl = 0.07$, $F = 0.04$ of a per cent. The introduction of these into the calculation is important in proportion as the amounts of the bases with which they combine are small in the rock.

A check on the results is furnished by the agreement of the sum of the calculated mineral components and the components not included in the calculation with the sum total of the analysis. This check cannot be absolutely exact because of errors in the determination of the last decimal figure in the calculation of each component throughout the process.

The rocks chosen to illustrate the method represent several cases. That of the toscanose (granodiorite), Table I, is the simplest case. $Al_2O_3$ and $SiO_2$, being in excess, yield normative corundum and quartz; the femic silicate being hypersthene.

The hessose (amphibole-gabbro), Table II, illustrates the method of adjusting $SiO_2$ between hypersthene and olivine.

The nordmarkose (litchfieldite), Table III, illustrates the method of distributing $SiO_2$ between albite and nephelite after reckoning the femic silicate as olivine. All the $Na_2O$ is first allotted to $Al_2O_3$, and $SiO_2$ is allotted to orthoclase, anorthite, and olivine; the remainder, 0.680 mol., is distributed according to the formulæ.

In the case of the laurdalose (laurdalite), Table IV, insufficient $Al_2O_3$ necessitates the formation of acmite molecules. After allotting $SiO_2$ to orthoclase, acmite, diopside, and olivine, the remainder, 0.522 mol., is distributed between albite and nephelite.

The vesuvose-albanose (leucitite), Table V, illustrates the case in which akermanite (melilite) is required to satisfy the calculation. After allotting $SiO_2$ to leucite, nephelite, anorthite, diopside, and olivine, there is a deficit of 0.069 mol. $SiO_2$. This is adjusted by the introduction of akermanite according to the formula, and the recalculation of diopside and olivine. It also illustrates the case of an intermediate rock, between Classes I and II.

### TABLE I.

### TOSCANOSE (GRANODIORITE) EL CAPITAN, YOSEMITE VALLEY, CAL.

*Bull. 168, U. S. Geol. Surv.*, p. 208.

| | Per cent. | Mol. | Ilm. | Mag. | Orth. | Alb. | An. | Cor. | Hyp. | Quartz. |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ... | 71.08 | 1.185 | .... | .... | 258 | 342 | 94 | .... | 27 | 464 |
| $Al_2O_3$ .. | 15.90 | .156 | .... | .... | 43 | 57 | 47 | 9 | .... | .... |
| $Fe_2O_3$ . | .62 | .004 | .... | 4 | .... | .... | .... | .... | .... | .... |
| FeO ... | 1.31 | .018 | 3 | 4 | .... | .... | .... | .... | 11 | .... |
| MgO... | .54 | .014 | .... | .... | .... | .... | .... | .... | 14 | .... |
| CaO ... | 2.60 | .047 | .... | .... | .... | .... | 47 | .... | .... | .... |
| $Na_2O$ .. | 3.54 | .057 | .... | .... | .... | 57 | .... | .... | .... | .... |
| $K_2O$ ... | 4.08 | .043 | .... | .... | 43 | .... | .... | .... | .... | .... |
| $H_2O+$ | .30 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| $H_2O-$. | none | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| $CO_2$ ... | tr | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| $TiO_2$... | .22 | .003 | 3 | .... | .... | .... | .... | .... | .... | .... |
| $P_2O_5$ .. | .10 | .000 | .... | .... | .... | .... | .... | .... | .... | .... |
| $SO_3$ ... | none | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Cl ..... | .02 | .000 | .... | .... | .... | .... | .... | .... | .... | .... |
| MnO... | .15 | .002 | .... | .... | .... | .... | .... | .... | 2 | .... |
| BaO ... | .04 | .000 | .... | .... | .... | .... | .... | .... | .... | .... |
| SrO.... | .02 | .000 | .... | .... | .... | .... | .... | .... | .... | .... |
| $ZrO_2$... | .08 | .000 | .... | .... | .... | .... | .... | .... | .... | .... |
| | 100.60 | | | | | | | | | |

| FORMULA. | MOL. WT. | | NORM. | | | | |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 464 × 60 | = quartz | = 27.84 | Q | 27.84 | Sal | 95.61 |
| $K_2O.Al_2O_3.6SiO_2$ | 43 × 556 | = orthoclase | = 23.91 | F | 66.85 | | |
| $Na_2O.Al_2O_3.6SiO_2$ | 57 × 524 | = albite | = 29.87 | | | | |
| $CaO.Al_2O_3 2.SiO_2$ | 47 × 278 | = anorthite | = 13.07 | | | | |
| $Al_2O_3$ | 9 × 102 | = corundum | = .92 | C | .92 | | |
| $MgO.SiO_2$ | 14 × 100 | = hypersthene | = 3.11 | P | 3.11 | Fem | 4.49 |
| $(Fe, Mn)O.SiO_2$ | 13 × 132 | | | | | | |
| $FeO.Fe_2O_3$ | 4 × 232 | = magnetite | = .93 | M | 1.38 | | |
| $FeO.TiO_2$ | 3 × 152 | = ilmenite | = .45 | | | | |
| | | | 100.10 | | | | |

CLASS I.

$$\frac{Sal}{Fem} = \frac{95.6}{4.5} > \frac{7}{1}$$

*Persalane.*

ORDER 4.

$$\frac{F}{Q} = \frac{66.8}{27.8} > \frac{5}{3} < \frac{7}{1}$$

*Britannare.*

RANG 2.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{100}{47} > \frac{5}{3} < \frac{7}{1}$$

*Toscanase.*

SUBRANG 3.

$$\frac{K_2O'}{Na_2O'} = \frac{43}{57} < \frac{5}{3} > \frac{3}{5}$$

*Toscanose.*

### TABLE II.

### HESSOSE (AMPHIBOLE GABBRO) BEAVER CREEK, BIG TREES QUADRANGLE, CAL.

*A. J. S.*, Vol. VIII (1899), p. 297; *Bull. 168*, U. S. G. S., p. 206.

| | Per Cent. | Mol. | Apat. | Ilm. | Mag. | Orth. | Alb. | An. | Diop. | Rem'der. | Hyp. | Oliv. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ .... | 47.27 | .788 | .. | .. | .. | 12 | 264 | 306 | 118 | 88 | 37 | 51 |
| $Al_2O_3$ ... | 20.82 | .204 | .. | .. | .. | 2 | 44 | 158 | .. | .. | .. | .. |
| $Fe_2O_3$ ... | 1.85 | .011 | .. | .. | 11 | .. | .. | .. | .. | .. | .. | .. |
| FeO ..... | 4.26 | .059 | .. | 11 | 11 | .. | .. | .. | | | .. | .. |
| MgO .... | 6.44 | .161 | .. | .. | .. | .. | .. | 19.8 | 59 | 139 | 37 | 102 |
| CaO..... | 13.02 | .232 | 15 | .. | .. | .. | .. | 158 | 59 | .. | .. | .. |
| $Na_2O$.... | 2.75 | .044 | 2.1 | .. | .. | .. | 44 | .. | .. | .. | .. | .. |
| $K_2O$ .... | .22 | .002 | .. | .. | .. | 2 | .. | .. | .. | .. | .. | .. |
| $H_2O+$ .. | 1.27 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $H_2O-$ .. | .08 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $TiO_2$ .... | .92 | .011 | .. | 11 | .. | .. | .. | .. | .. | .. | .. | .. |
| $P_2O_5$ .... | .74 | .005 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Cl....... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $Cr_2O_3$ ... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| MnO .... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SrO ..... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $V_2O_3$.... | .02 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $FeS_2$ .... | .20 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | 99.86 | | | | | | | | | | | |

$$x + \frac{y}{2} = 88\ SiO_2$$
$$x + y = 139\ (Mg, Fe)\ O$$
$$y = 102$$
$$x = 37$$

| FORMULA. | MOL. WT. | | | NORM. | | | | |
|---|---|---|---|---|---|---|---|---|
| $K_2O.Al_2O_3.6SiO_2$ | $2 \times 556$ | = orthoclase | = | 1.11 | F | 68.09 | Sal | 68.09 |
| $Na_2O.Al_2O_3.6SiO_2$ | $44 \times 524$ | = albite | = | 23.06 | | | | |
| $CaO.Al_2O_3.2SiO_2$ | $158 \times 278$ | = anorthite | = | 43.92 | | | | |
| $CaO.SiO_2$ | $59 \times 116$ | = diopside | = | 13.10 | P + O | 24.77 | Fem | 30.74 |
| $MgO.SiO_2$ | $48 \times 100$ | | | | | | | |
| $FeO.SiO_2$ | $11 \times 132$ | | | | | | | |
| $MgO\ SiO_2$ | $30 \times 100$ | = hypersthene | = | 3.92 | | | | |
| $FeO.SiO_2$ | $7 \times 132$ | | | | | | | |
| $2MgO.SiO_2$ | $83 \times 70$ | = olivine | = | 7.75 | | | | |
| $2FeO.SiO_2$ | $19 \times 102$ | | | | | | | |
| $FeO.Fe_2O_3$ | $11 \times 232$ | = magnetite | = | 2.55 | M | 4.22 | | |
| $FeO.TiO_2$ | $11 \times 152$ | = ilmenite | = | 1.67 | | | | |
| $3CaO.P_2O_5$ | $5 \times 310$ | = apatite | = | 1.55 | A | 1.75 | | |
| $FeS_2$ | | pyrite | = | .20 | | | | |
| | | etc. | = | 1.37 | | | | |
| | | | | 100.20 | | | | |

CLASS II.

$$\frac{Sal}{Fem} = \frac{68.09}{30.74} < \frac{7}{1} > \frac{5}{3}$$

*Dosalane.*

ORDER 5.

$$\frac{F}{Q} = \frac{68.09}{0} > \frac{7}{1}$$

*Germanare.*

RANG 4.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{46}{158} < \frac{3}{5} > \frac{1}{7}$$

*Hessase.*

SUBRANG 3.

$$\frac{K_2O'}{Na_2O'} = \frac{2}{44} < \frac{1}{7}$$

*Hessose.*

## TABLE III.

### NORDMARKOSE (LITCHFIELDITE), LITCHFIELD, ME.

*Bull. 168, U. S. Geol. Surv.*, p. 21.

| | Per cent. | Mol. | Orth. | Alb. | Nep. | An. | Cor. | Mag. | Oliv. |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ...... | 60.39 | 1.006 | c.b<br>300 | 612<br>680<br>102 | 68<br><br>34 | .6''<br>10 | .. | .. | 16 |
| $Al_2O_3$..... | 22.57 | .221 | ''50 | 136 | | 1-5 | 30 | .. | .. |
| $Fe_2O_3$ .... | .42 | .003 | .14 | ... | .. | .. | .. | 3 | .. |
| FeO ...... | 2.26 | .030 8 | ... | ... | .. | .. | .. | 3 | 27 |
| MgO...... | .13 | .003 | ... | ... | .. | .. | .. | .. | 3 |
| CaO....... | .32 | .005 | ... | ... | .. | 5 | .. | .. | .. |
| | | | | 102 | 34 | | | | |
| $Na_2O$..... | 8.44 | .136 q | ... | 136 | | .. | .. | .. | .. |
| $K_2O$...... | 4.77 | .050 | 50 | ... | .. | .. | .. | .. | .. |
| $\left.\begin{matrix}H_2O+\\H_2O-\end{matrix}\right\}$ .. | .57 | .... | ... | ... | .. | .. | .. | .. | .. |
| MnO...... | .08 | .001 | ... | ... | .. | .. | .. | .. | 1 |
| | 99.95 | | | | | | | | |

$$1.006-(0.300+0.010+0.016)=0.680$$
$$6x+2y=680\ (SiO_2)$$
$$x+y=136\ (Na_2O)$$
$$x=102$$
$$y=34$$

In the rock the extra $Al_2O_3$ enters mica, combining with the olivine and magnetite molecules and because of low magnesia making lepidomelane.

| FORMULA. | MOL. WT. | NORM. | | | | |
|---|---|---|---|---|---|---|
| $K_2O.Al_2O_3.6SiO_2$ | $50\times556$ | = orthoclase = | 27.80 | F | Sal | 95.35 |
| $Na_2O.Al_2O_3.6SiO_2$ | $102\times524$ | = albite = | 53.45 | | | |
| $CaO.Al_2O_3.2SiO_2$ | $5\times278$ | = anorthite = | 1.39 | | | |
| $Na_2O.Al_2O_3.2SiO_2$ | $34\times284$ | = nephelite = | 9.66 | L | | |
| $Al_2O_3$ | $30\times102$ | = corundum = | 3.06 | C | | |
| $FeO.Fe_2O_3$ | $3\times232$ | = magnetite = | .70 | M | Fem | 3.81 |
| $2MgO.SiO_2$ | $3\times70$ | = olivine = | 3.11 | O | | |
| $2FeO.SiO_2$ | $28\times102$ | | | | | |
| | | $H_2O$ = | .57 | | | |
| | | | 99.73 | | | |

CLASS I.

$$\frac{\text{Sal}}{\text{Fem}}=\frac{95.35}{3.81}>\frac{7}{1}$$

*Persalane.*

ORDER 5.

$$\frac{F}{L}=\frac{82.64}{9.66}>\frac{7}{1}$$

*Canadare.*

RANG 1.

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{186}{5}>\frac{7}{1}$$

*Nordmarkase.*

SUBRANG 4.

$$\frac{K_2O'}{Na_2O'}=\frac{50}{136}<\frac{3}{5}>\frac{1}{7}$$

*Nordmarkose.*

## TABLE IV.

### LAURDALOSE (LAUDALITE), WEST OF POLLEN, LAUGENDAL, NORWAY.

BRÖGGER, W. C., *Die Eruptivgesteine des Christiania Gebietes*, Vol. III, p. 19.

| | Per cent. | Mol. | Ap. | Ilm. | Orth. | Alb. | Nep. | Acm. | Mag. | Diop. | Oliv. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 366 | 156 | | | | |
| $SiO_2$ .... | 56.35 | .939 | .. | .. | 336 | 522 | | 16 | .. | 62 | 3 |
| | | | | | | 61 | 78 | | | | |
| $Al_2O_3$ ... | 19.85 | .195 | .. | .. | 56 | 139 | | .. | .. | .. | .. |
| $Fe_2O_3$ ... | 1.91 | .012 | .. | .. | ... | ... | ... | 4 | 8 | .. | .. |
| FeO ..... | 2.03 | .028 | .. | 12 | ... | ... | ... | .. | 8 | 7 | 1 |
| MgO .... | 1.17 | .029 | .. | .. | ... | ... | ... | .. | .. | 24 | 5 |
| CaO ..... | 2.60 | .046 | 15 | .. | ... | ... | ... | .. | .. | 31 | .. |
| | | | | | | 61 | 78 | | | | |
| $Na_2O$.... | 8.89 | .143 | .. | .. | ... | 139 | | 4 | .. | .. | .. |
| $K_2O$..... | 5.31 | .056 | .. | .. | 56 | ... | ... | .. | .. | .. | .. |
| $H_2O$ .... | .70 | .... | .. | .. | ... | ... | ... | .. | .. | .. | .. |
| $TiO_2$ .... | 1.00 | .012 | .. | 12 | ... | ... | ... | .. | .. | .. | .. |
| $P_2O_5$ .... | .67 | .005 | 5 | .. | ... | ... | ... | .. | .. | .. | .. |
| | 100.68 | | | | | | | | | | |

$$6x + 2y = 522\ (SiO_2)$$
$$x + y = 139\ (Na_2O)$$
$$x = 61$$
$$y = 78$$

| FORMULA. | MOL. WT. | | NORM. | | | | |
|---|---|---|---|---|---|---|---|
| $K_2O.Al_2O_3.6SiO_2$ | 56 × 556 | = orthoclase = | 31.14 | F | 63.10 | | |
| $Na_2O.Al_2O_3.6SiO_2$ | 61 × 524 | = albite = | 31.96 | | | Sal | 85.25 |
| $Na_2O.Al_2O_3.2SiO_2$ | 78 × 284 | = nephelite = | 22.15 | L | 22.15 | | |
| $Na_2O.Fe_2O_3.4SiO_2$ | 4 × 462 | = acmite = | 1.85 | | | | |
| $CaO.SiO_2$ | 31 × 116 | | | P | 8.77 | | |
| $MgO.SiO_2$ | 24 × 100 | = diopside = | 6.92 | | | | |
| $FeO.SiO_2$ | 7 × 132 | | | | | | |
| $2MgO.SiO_2$ | 5 × 70 | = olivine = | .46 | O | .46 | Fem | 14.45 |
| $2FeO.SiO_2$ | 1 × 102 | | | | | | |
| $FeO.Fe_2O_3$ | 8 × 232 | = magnetite = | 1.86 | M | 3.68 | | |
| $FeO.TiO_2$ | 12 × 152 | = ilmenite = | 1.82 | | | | |
| $3CaO.P_2O_5$ | 5 × 310 | = apatite = | 1.55 | A | 1.55 | | |
| | | $H_2O$ = | .70 | | | | |
| | | | 100.41 | | | | |

CLASS II.

$$\frac{Sal}{Fem} = \frac{85.25}{14.45} < \frac{7}{1} > \frac{5}{3}$$

*Dosalane.*

ORDER 6.

$$\frac{F}{L} = \frac{63.10}{22.15} < \frac{7}{1} > \frac{5}{3}$$

*Norgare.*

RANG 1.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{195}{0} > \frac{7}{1}$$

*Laurdalase.*

SUBRANG 4.

$$\frac{K_2O'}{Na_2O'} = \frac{56}{139} < \frac{3}{5} > \frac{1}{7}$$

*Laurdalose.*

## TABLE V.

### VESUVOSE-ALBANOSE (LEUCITITE). CAPO DI BOVE, ITALY.

*A. J. S.*, Vol. IX (1900), p. 56.

| | Per cent. | Mol. | Ilm. | Leuc. | Nep. | An. | Mag. | Tentative. | | Deficit. | Final. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Diop. | Oliv. | | Ak.[1] | Diop. | Oliv. |
| $SiO_2$ . | 45.99 | .767 | .... | 376 | 70 | 78 | .... | 298 | 14 | 69 | 69 | 114 | 60 |
| $Al_2O_3$ | 17.12 | .168 | .... | 94 | 35 | 39 | .... | .... | .... | .... | .... | .... | .... |
| $Fe_2O_3$ | 4.17 | .026 | .... | .... | .... | .... | 26 | .... | .... | .... | .... | .... | .... |
| FeO . . | 5.38 | .075 | 5 | .... | .... | .... | 26 | 37 | 7 | .... | .... | 14 | 30 |
| MgO . . | 5.30 | .133 | .... | .... | .... | .... | .... | 112 | 21 | .... | .... | 43 | 90 |
| CaO . . | 10.47 | .187 | .... | .... | .... | 39 | .... | 148 | .... | .... | 92 | 56 | .... |
| $Na_2O$ . | 2.18 | .035 | .... | .... | 35 | .... | .... | .... | .... | .... | .... | .... | .... |
| $K_2O$ . . | 8.97 | .094 | .... | 94 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| $H_2O$ . | .45 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| $TiO_2$ . | .37 | .005 | 5 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| MnO . . | tr | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| BaO . . | .25 | .001 | .... | .... | .... | .... | .... | 1 | .... | .... | .... | 1 | .... |
| SrO . . | none | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 100.65 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |

[1] Mol. of akermanite $= y = \frac{69}{3} = 23$.

| FORMULA. | MOL. WT. | | NORM. | | |
|---|---|---|---|---|---|
| $K_2O.Al_2O_3.4SiO_2$ | 94 × 436 | = leucite = | 40.98 | L = 50.92 | Sal 61.76 |
| $Na_2O.Al_2O_3 2SiO_2$ | 35 × 284 | = nephelite = | 9.94 | | |
| $CaO\ Al_2O_3.2SiO_2$ | 39 × 278 | = anorthite = | 10.84 | F = 10.84 | |
| $CaO.SiO_2$ | 57 × 116 | = diopside = | 12.76 | P = 12.76 | Fem 38.20 |
| $MgO.SiO_2$ | 43 × 100 | | | | |
| $FeO.SiO_2$ | 14 × 132 | | | | |
| $2MgO.SiO_2$ | 90 × 70 | = olivine = | 9.36 | O = 18.65 | |
| $2FeO.SiO_2$ | 30 × 102 | | | | |
| $4CaO.3SiO_2$ | 23 × 404 | = akermanite = | 9.29 | | |
| $FeO.Fe_2O_3$ | 26 × 232 | = magnetite = | 6.03 | M = 6.79 | |
| $FeO.TiO_2$ | 5 × 152 | = ilmenite = | .76 | | |
| | | $H_2O$ | .45 | | |
| | | | 100.41 | | |

CLASS III.

$$\frac{\text{Sal}}{\text{Fem}} = \frac{61.76}{38.20} < \frac{5}{3} > \frac{3}{5}$$

*Dosalane-salfemane.*

ORDER 6.

$$\frac{F}{L} = \frac{10.84}{50.92} < \frac{3}{5} > \frac{1}{7}$$

*Campanare-bohemare.*

RANG 2.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{129}{39} < \frac{7}{1} > \frac{5}{3}$$

*Vesuvase-albanase.*

SUBRANG 2.

$$\frac{K_2O'}{Na_2O'} = \frac{94}{35} < \frac{7}{1} > \frac{5}{3}$$

*Vesuvose-albanose.*

The janeirose (pseudo-leucite-sodalite-tinguaite), Table VI, illustrates the method of calculating leucite and orthoclase, as well as sodalite and noselite. After allotting $SiO_2$ to nephelite, acmite, diopside, and olivine, the remainder of $SiO_2$ is 0.546 mol.

## TABLE VI.

### JANEIROSE (PSEUDO-LEUCITE-SODALITE-TINGUAITE) BEAVER CREEK, BEARPAW MOUNTAINS, MONT.

*Bull. 168, U. S. Geol. Surv.*, p. 136.

| | Per cent. | Mol. | Ilm. | Fluor. | NaCl. | $Na_2SO_4$. | Calcite. | Orth. | Leuc. | Nep.[1] | Acm. | Diop. | Oliv. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . | 51.93 | .866 | .. | .. | .. | .. | .. | $\underbrace{390 \mid 156}_{546}$ | | 192 | 88 | 38 | 2 |
| $Al_2O_3$ | 20.29 | .200 | .. | .. | .. | .. | .. | $\underbrace{65 \mid 39}_{104}$ | | 96 | .. | .. | .. |
| $Fe_2O_3$ | 3.59 | .022 | .. | .. | .. | .. | .. | .. | .. | .. | 22 | .. | .. |
| FeO .. | 1.20 | .018 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | 14 | 2 |
| MgO .. | .22 | .006 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 5 | 1 |
| CaO .. | 1.65 | .030 | .. | 7 | .. | .. | 6 | .. | .. | .. | .. | 17 | .. |
| $Na_2O$ . | 8.49 | .137 | .. | .. | 10 | 9 | .. | .. | .. | 96 | 22 | .. | .. |
| $K_2O$ .. | 9.81 | .104 | .. | .. | .. | .. | .. | $\underbrace{65 \mid 39}_{104}$ | | .. | .. | .. | .. |
| $H_2O+$ | .10 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $H_2O-$ | .99 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $TiO_2$ .. | .20 | .002 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $P_2O_5$ . | .06 | .000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SrO .. | .07 | .001 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. |
| BaO .. | .09 | .001 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. |
| $SO_3$ .. | .67 | .009 | .. | .. | .. | 9 | .. | .. | .. | .. | .. | .. | .. |
| $CO_2$ .. | .25 | .006 | .. | .. | .. | .. | 6 | .. | .. | .. | .. | .. | .. |
| Cl .... | .70 | .020 | .. | .. | 20 | .. | .. | .. | .. | .. | .. | .. | .. |
| F .... | .27 | .014 | .. | 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | 100.58 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | .27 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | 100.31 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

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[1] For nephelite, sodalite, and noselite.

$$6x + 4y = 546\ (SiO_2)$$
$$x + y = 104\ (K_2O)$$
$$x = 65$$
$$y = 39$$

| FORMULA. | MOL. WT. | | NORM. | | | |
|---|---|---|---|---|---|---|
| $K_2O.Al_2O_3.6SiO_2$ | 65 × 556 | orthoclase | 36.14 | F | 36.14 | Sal. 82.75 |
| $K_2O.Al_2O_3.4SiO_2$ | 39 × 436 | leucite | 17.00 | L | 46.61 | |
| $Na_2O.Al_2O_3.2SiO_2$ | 48 × 284 | nephelite | 13.63 | | | |
| $3(Na_2O.Al_2O_3.2SiO_2)2(NaCl)$ | 10 × 969 | sodalite | 9.69 | | | |
| $2(Na_2O.Al_2O_3.2SiO_2)Na_2SO_4$ | 9 × 699 | noselite | 6.29 | | | |
| $Na_2O.Fe_2O_3.4SiO_2$ | 22 × 462 | acmite | 10.16 | P | 14.48 | Fem. 15.60 |
| $CaO.SiO_2$ | 17 × 116 | diopside | 4.32 | | | |
| $MgO.SiO_2$ | 5 × 100 | | | | | |
| $FeO.SiO_2$ | 14 × 132 | | | | | |
| $2MgO.SiO_2$ | 1 × 70 | olivine | .27 | O | .27 | |
| $2FeO.SiO_2$ | 2 × 102 | | | | | |
| $FeO.TiO_2$ | 2 × 152 | ilmenite | .30 | M | .30 | |
| $CaF_2$ | 7 × 78 | fluorite | .55 | A | .55 | |
| $CaO.CO_2$ | 6 × 100 | calcite | .60 | | | |
| | | $H_2O$ | 1.09 | | | |
| | | | 100.04 | | | |

| CLASS II. | ORDER 7. | RANG 1. | SUBRANG 3. |
|---|---|---|---|
| $\frac{Sal}{Fem} = \frac{82.75}{15.60} < \frac{7}{1} > \frac{5}{3}$ | $\frac{F}{L} = \frac{36.14}{46.61} < \frac{5}{3} > \frac{3}{5}$ | $\frac{K_2O' + Na_2O'}{CaO'} = \frac{219}{0} > \frac{7}{1}$ | $\frac{K_2O'}{Na_2O'} = \frac{104}{115} < \frac{5}{3} > \frac{3}{5}$ |
| *Dosalane.* | *Italare.* | *Lujavrase.* | *Janeirose.* |

*The calculation of the norm from the mode.*— Having described the process by which the norm may be calculated from the chemical analysis of a rock, there remains the discussion of the process by which it may be calculated directly from the actual mineral composition of the rock without having the chemical analysis.

The first requisite in this case is a knowledge of the actual mineral composition of a particular rock, and it is evident that not every rock is sufficiently well crystallized to permit even an approximate estimate of the kinds and quantities of all the minerals present. Consequently there are very many rocks in which the norm cannot be calculated directly from the rock without recourse to a chemical analysis. These are partly glassy rocks, and those that are so fine-grained that the individual mineral components cannot be identified and measured.

But it is possible with some rocks to determine very closely the proportions of the minerals present in them. Such rocks are holocrystalline, and the crystals are sufficiently large to permit their individuality and outline to be recognized. With such rocks the method of determining the quantity of all the mineral components is as follows:

Estimate by accurate measurement the volumetric proportions of all the component minerals. This may be accomplished by measuring with a micrometer the diameters of each crystal in lines across thin sections of a rock, care being taken to measure a distance at least one hundred times the average grain of the rock.[1] The proportions found for the lengths of diameters of the various components will correspond to those of their volumes. Several other methods have been devised which are less accurate and need not be described here.

The volumetric proportions are to be reduced to relative masses by multiplying the volume of each mineral by its specific gravity and reducing the total to one hundred parts.

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[1] ROSIWAL, *Verh. Wien. Geol. Reichs-Anst.*, Vol. XXXII, pp. 143 ff., 1898.

Accurate quantitative determination of the mineral components of rocks by optical methods is difficult with coarse-grained and coarsely porphyritic rocks as well as with extremely fine-grained ones. When the rock contains large crystals a comparatively large area of it must be measured to obtain correct proportions of the component minerals. A few thin sections are not adequate. The measurements must be made megascopically. The same is true when there are large phenocrysts. A sufficiently large area of surface must be measured to furnish a correct estimate of the relative proportions of the several kinds of phenocrysts and the groundmass. Subsequently the groundmass may be studied and measured with a microscope and the two sets of measurements combined.

In very fine-grained rocks, where the kinds of minerals composing them can all be identified, the accuracy of measurements of the diameters of crystals with a microscope is affected by the overlapping of crystals within the section, and it is found by experience that the amount of the colored crystals is overestimated, while that of the colorless ones is underestimated. This is particularly the case where the thickness of crystals is a fraction of the thickness of the rock section, as with microlites and minute inclusions. It will be necessary to determine corrections to be applied in such cases by working on microcrystalline or microlitic rocks whose chemical composition has been determined.

If all of the minerals actually present in a holocrystalline rock are standard minerals, salic or femic, there may still be uncertainty as to the norm, since the proportions of the standard minerals actually developed may not accord with those constituting the norm. In all cases it is necessary to calculate the norm from the actual mineral composition quantitatively determined by estimating the chemical composition of the rock from that of each of its component minerals, and from this analysis deducing the norm as in the first method described.

This involves the determination of the chemical composition of the actual minerals present in the rock. For a certain number this may be based on optical investigation. The composition of minerals with constant or comparatively simple molecules may be taken as that of the ideal molecule, as, for example, in such minerals as quartz, orthoclase, albite, anorthite, leucite, nephelite, apatite, zircon, titanite, etc.

The proportions of the chemical components reckoned as oxides belonging to each of these minerals must be multiplied by the percentage weight of each mineral to furnish the chemical components of the whole rock. Thus 35 per cent. of quartz = 35 per cent. of $SiO_2$; 10 per cent. of orthoclase = 6.47 per cent. of $SiO_2$, 1.83 per cent. $Al_2O_3$, 1.69 per cent. $K_2O$.

When the mineral has no fixed chemical molecule, as, for example, olivine, in which Mg and Fe are variable, it is necessary to consider the composition most likely to obtain for the mineral in a rock of about the character of the one under investigation, or to observe more specifically the optical properties of the mineral where these are characteristic of the chemical composition.

For the plagioclase feldspars the optical properties have been elaborately investigated and are well known. It is necessary to determine as accurately as possibly by Michel-Lévy[1] methods, aided by Becke's[2] method, the composition of the striated feldspars, noting the variation in zones, and estimating approximately the average composition of the crystals. The ratios of Ab to An must be transposed into ratios between $Na_2O$ and CaO by halving the value of Ab. For the reason that Ab stands for the formula $NaAlSi_3O_8$ and An for the formula $CaAl_2Si_2O_8$. In the first there is only one Na, hence Ab : An : : Na : Ca. When we express the composition of albite by $Na_2O.Al_2O_3.6SiO_2$, we are using 2Ab. And in estimating $Na_2O$ from the albite combined with anorthite in a plagioclase feldspar we obtain one-half as many molecules of $Na_2O$ as we have Ab derived from the familiar symbol of a plagioclase, $Ab_nAn_m$.

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[1] *Étude sur la détermination des feldspaths* (Paris), 1re fasicule, 1894; 2me fasicule, 1896.

[2] *Sitzungsb. Akad. Wiss. Wien.*, Vol. CII, Part I, pp. 358–76, 1893.

A less precise method may be used, which is sufficiently accurate considering the inaccuracy of the approximation to the average composition of zonally built feldspars, namely, to apply the ratio Ab / An obtained optically directly to the percentage weights of plagioclase. Thus 50 per cent. of plagioclase, whose average composition has been estimated at $Ab_3An_2$, may be separated into 30 per cent. albite and 20 per cent. anorthite with approximate correctness.

In the case of hornblende, augite, and mica, the color and optical properties are undoubtedly equally characteristic, but they have not received sufficient attention to permit of the same direct application. They are, however, guides to the choice of typical formulas or chemical analyses, which may be used temporarily in place of more exact methods.

For this purpose tables have been arranged giving the chemical analyses of certain rock-making alferric minerals, and also the analyses of the rocks in which these minerals occur. From these it is possible to select cases corresponding more or less closely to those in the rock whose norm is to be determined. For it appears from data already at hand that the chemical composition of each mineral in a rock bears such a relation to the chemical composition of the whole rock, that minerals of the same kind, for example the hornblendes, when they occur in similar rocks have very nearly the same composition. The compositions of the hornblendes and micas in the granodiorite of the Sierra Nevada, California, and of those in the very similar quartz-monzonite of Butte, Montana, are nearly the same.

For minerals with variable composition, then, select from Tables of Analyses the analysis of the mineral corresponding most closely to the one in the rock in question, considering both its optical characters and the general character of the rock in which it occurs, and reduce its several chemical constituents to the proper amount by multiplying by the percentage of the mineral as determined from the rock.

Having reduced each mineral to its chemical constituents the sum of the constituents will represent the chemical composition of the rock. From this the salic and femic minerals may be calculated as in the first instance, and the norm determined.

In many cases it will not be necessary to reduce all of the minerals to their chemical constituents in order to determine the norm. For the minerals may be largely salic or femic as they occur in the rock. This is the case with the feldspars, feldspathoids (lenads), and quartz, with orthorhombic pyroxenes, olivine, diopside, magnetite, etc.

It is chiefly the aluminous ferromagnesian minerals that require reduction. And for first approximations the proportions of salic and femic constituents contained in these minerals are given in Tables XII, XIII, and XIV at the end of this Part.

From these it is seen that in aluminous pyroxenes the proportion of the salic component is often 0.10, and does not exceed 0.23. The femic component is 0.90 in most cases, and rarely 0.77.

For hornblende and closely related amphiboles the salic component is from 0.20 to 0.34, and in the more sodic amphiboles it is about 0.20.

For micas the two components are nearly equal, that is, 0.50 each.

When the amounts of salic and femic components are known the Class of the rock is established. For rocks of the first three Classes the next step is the determination of the relative amounts of quartz, feldspar, and feldspathoid. For persalane rocks this is comparatively simple, since the other minerals are present in small amounts. But as the amount of mica, amphibole, and augite increases it becomes necessary to determine more accurately the nature of the salic component involved in each, in order to adjust the silica before reckoning the proportions of quartz, feldspar, or feldspathoids. In such cases the first method must be followed, or the aluminous ferromagnesian minerals must be resolved into aluminous and non-aluminous portions and the silica adjusted to these portions and to the other salic and femic components, according to the method given for calculating the standard minerals.

The determinations of Rang and Subrang as well as of Grad and Subgrad follow the calculation of the chemical components.

### THE CALCULATION OF THE MODE FROM THE CHEMICAL ANALYSIS OF A ROCK.

This is often desired in order to compare the two, and to determine the amount of the chemical composition of some of the component minerals, not otherwise determinable.

But it is evident that the knowledge of the actual minerals present in the rock cannot be learned directly from the chemical analysis, since various mineral combinations may be formed within certain limits It is therefore necessary to determine the presence of these minerals by a study of the rock, and this involves microscopical investigation in nearly all cases. This has generally meant the simple enumeration of the kinds of minerals present, with the crudest statement of their relative proportions.

In some instances this would furnish data enough for the solution of the problem, but it is clear that such cases must be those in which all the minerals present are salic and femic, without intermediate, alferric, kinds, or those cases in which the alferric minerals are developed to their limit, as for example, hornblende present to the exclusion of diopside, or to the exclusion of hypersthene and olivine; biotite present to the exclusion of hypersthene and olivine, or to the exclusion of potash-feldspathic minerals, or to the exhaustion of available alumina.

Under such circumstances it would be possible to calculate the composition and proportions of the actual minerals. But even in these cases the variable chemical character of amphiboles and micas renders the solution of the problem untrustworthy unless the composition of the particular amphibole or mica be known exactly or approximately.

This involves the separation and analysis of one or both of these minerals, or the reasonable assumption that they have approximately the same composition as other amphiboles and micas which have been analyzed.

Further consideration of the problem will convince one that where augites, amphiboles, and micas occur with femic minerals, such as diopside, hypersthene, and olivine, the problem cannot be solved by simply determining the kinds of minerals present in the rock. The algebraic equations involve too many unknown quantities. In other words, there may be variable amounts of the same minerals developed from chemically similar magmas. It becomes necessary then to determine the relative amounts of several of these minerals, according to the number of them, in order to reduce the number of unknown quantities in the algebraic equations. Then it is possible, with part of the problem solved by microscopical study, to complete it by estimating the remaining factors from the chemical analysis of the rock. That is to say, in most cases the microscopical and chemical methods must supplement one another.

Thus it is possible to calculate the probable composition of a hornblende in a given rock when all the other minerals have comparatively simple, or fixed, molecules, and when the quantity of the hornblende has been determined optically. In another case, if hornblende has been separated from the rock and analyzed, it is possible to calculate the probable composition of a biotite present, when the proportions of these two minerals are known, and the other minerals in the rock have fixed molecules.

The same process may be used to determine the composition of the groundmass, when the character and percentages of the phenocrysts have been determined.

The method of calculation, which is illustrated by the case of the Butte granite given on a subsequent page, may be stated as follows:

Starting with the chemical analysis of the rock, reduce it to molecular proportions by dividing the percentage of each chemical component by its molecular weight.

Deduct from these molecules the molecules belonging to such minerals as have been chemically and quantitatively determined.

The remaining oxide molecules are to be distributed among the minerals with fixed molecules, whose quantity, however, is undetermined, by assigning to each mineral its proper oxide molecules in the proportions in which they occur in the ideal mineral molecule, as, for example; for orthoclase, $1K_2O.1Al_2O_3.6SiO_2$, and further, by indicating the number of molecules of each mineral by an algebraic symbol or letter. Thus, if there are $x$ molecules of orthoclase, there must be assigned to them $xK_2O.xAl_2O_3.6xSiO_2$. The sum of all these assigned oxide molecules must equal the total amount of a particular chemical component in the rock after deducting that belonging to the minerals whose composition and quantity have been determined.

If there are more variable quantities than equations, that is, in general, more kinds of minerals than chemical components, it is necessary to reduce the number of unknown quantities by fixing the relative amounts of several minerals, or by stating their actual amounts.

### THE CALCULATION OF ALFERRIC MINERALS.

As pointed out in the discussion of the classification of igneous rocks on a basis of salic and femic minerals, the reasons for omitting the alferric minerals are their variable and complex composition, our inadequate knowledge of the chemical character of the amphiboles and micas, and the inconstancy of their crystallization from magmas of any given chemical composition.

The questions naturally arise, How may these minerals be introduced into the calculation of the mineral composition of rocks from rock analyses ? And what modifications of the norm would follow their introduction ?

These questions, though not important for the classification of rocks according to the system here proposed, are of interest because of their relation to the general problem of chemico-mineralogical classification and the possibilities of its assuming a more elaborate form than that given it by us. The discussion of them emphasizes the relations between the aluminous ferromagnesian minerals and the salic and femic minerals, and makes evident the effect of the crystallization of the alferric minerals in a given magma upon the proportions of the other minerals.

We shall consider the problem of converting portions of salic and femic minerals, already calculated from the analysis of a rock, into alferric minerals. The minerals in question are: aluminous pyroxenes, aluminous amphiboles, micas and garnets. Rarer minerals of this kind will not be considered. As to the chemical composition of these minerals, it is known that the amounts of alumina and ferric oxide in monoclinic pyroxenes, amphiboles, and micas vary considerably in different cases, so that no simple statement can be made regarding the ratios of alumina to other constituents in these minerals. Moreover, there is no fixed relation between the amount of aluminous ferromagnesian minerals actually crystallized in a rock and the chemical composition of its magma. However, a study of the chemical composition of these minerals, so far as they have been analyzed, shows that their composition bears some relation to that of the magma from which they crystallized. In order to present this relationship as clearly as possible, Tables XII, XIII, and XIV have been arranged, as already mentioned, giving the chemical analyses of aluminous pyroxenes, amphiboles, and micas, and those of the rocks from which they were separated. It is evident from these tables that there is need for much thorough chemical investigation of the rock-making pyroxenes, amphiboles, and micas before we shall be in a position to cope successfully with the problem before us. For the present we can explain the method of dealing with the known factors in the problem and indicate that which may be pursued in doubtful cases.

The solution of the problem involves the transfer of alumina from salic to femic molecules, the necessity of introducing it in proportions corresponding to the known composition of these minerals in each case, the consequent readjustment of molecules among the femic minerals, and the disarrangement and readjustment of molecules among the salic minerals.

The process appears at first sight complex, but only involves simple algebra, and when applied to a concrete example is not very intricate. Its value consists in familiarizing the student or investigator with the interdependence of the various mineral molecules in an igneous rock, and with the ranges of variation possible within rocks of the same chemical composition.

The minerals in question being characterized by a variable content of alumina, it is of first importance to note the amount of alumina present in different cases and to consider what transfer of chemical elements from salic to femic molecules would be necessary in order to produce such aluminous ferromagnesian minerals without destroying the stoichiometric proportions in the remaining salic and femic minerals.

In the case of a rock in which the calculation of the standard mineral composition showed the presence of an excess of $Al_2O_3$ over that required to form salic minerals it is evident that $Al_2O_3$ may be introduced into the ferromagnesian minerals by transferring it from this extra $Al_2O_3$.

But in the great majority of rocks there is no excess of $Al_2O_3$ in the sense here employed, and the production of aluminous ferromagnesian minerals affects the standard feldspathic molecules, so that the transfer of $Al_2O_3$ necessitates the transfer of those chemical bases united with it in equal proportions, namely, calcium, sodium, and potassium.

Each of these elements may enter into the composition of the minerals to be developed, whose molecules are more complex than those of femic minerals. A study of the analyses of the minerals in question shows that sodium enters into aluminous amphiboles independently of the acmite-riebeckite molecule ($Na_2O.Fe_2O_3.4SiO_2$), and that potassium also does, but to so small an extent in most instances that the error of estimating all of the alkali molecules as $Na_2O$ is negligible. Conversely, potassium enters largely into the micas, and the sodium present is so small that the alkali molecules in mica may be calculated as though wholly $K_2O$ without notable error.

Several chemico-mineralogical relations appear to control the amount of alumina, lime, and alkalies that may be transferred from salic to femic minerals to form alferric minerals. And since the transfer of $Al_2O_3$ involves the CaO, $K_2O$, and $Na_2O$ to various degrees, it is convenient to compare the amount of $Al_2O_3$ to be transferred with the principal one of these components taking part in the aluminous ferromagnesian mineral. This component becomes a unit of comparison for the other constituents of the particular mineral. In the pyroxenes and amphiboles CaO is the component next to $Al_2O_3$ most involved in the change. It becomes the unit of comparison in these minerals. In the micas $K_2O$ plays this rôle.

The molecular relations which must be taken into account are expressed by ratios in the Tables XII, XIII, XIV at the end of this Part, and may be summed up as follows:

*Aluminous pyroxenes* (*Table XII*).—1. The ratio of $Al_2O_3$ to CaO ranges from almost nothing to 0.23. From these data the maximum limit is

$$\frac{Al_2O_3}{CaO} = 0.23 \,.$$

2. The nearly equal proportions between $Fe_2O_3$ and $Na_2O$ indicate that the soda is present in the acmite molecule.

3. The generally small ratio between $Na_2O$ and CaO. The ratio $\frac{Na_2O}{CaO}$ is less than 0.1 in most cases. Moreover, the presence of a notable amount of acmite molecule is indicated by the optical properties of the pyroxene.

4. The nearly constant ratio between $MgO+FeO$ and CaO, which is approximately

$$\frac{MgO + FeO}{CaO} = 1 \,.$$

5. The $SiO_2 + TiO_2$ is approximately equal to the number of molecules of $MgO + FeO + CaO + 4Na_2O$, corresponding to pyroxene molecules $(MgFe)O \,.\, CaO \,.\, 2SiO_2$ and $Na_2O \,.\, Fe_2O_3 \,.\, 4SiO_2$ and $(Mg, Fe)O. \,(Al, Fe)_2O_3 \,.\, SiO_2$.

*Aluminous amphiboles* (*Table XIII*).—The relations are less definite. There is a wide range in chemical composition, and it will be necessary to consider special kinds of amphibole in different cases.

*a*) 1. For *hornblende* occurring in rocks with lime-soda-feldspar the ratio of $Na_2O$ to CaO ranges from 0.08 to 0.21, while for hornblende in one alkali feldspathic rock it is 0.28, and for somewhat similar amphiboles, barkevikite and hastingsite, it reaches 0.35 and 0.43.

2. The ratio of $Al_2O_3$ to CaO ranges from 0.32 to 0.67 in the first mentioned cases, common hornblende, and from 0.44 to 0.85 in the second.

3. The ratio of MgO + FeO to CaO ranges from 1.73 to 2.72, being nearly 2.2 in most cases. It is not 3, as given in the text-books generally.

4. It is to be noted that in hornblende in the more calcic rocks the ratio of MgO to FeO is 2 or more (from 2 to 4), while in those in the perfelic, alkalic rocks, this ratio is less than 1 (from 0.1 to 0.6). In other words, magnesia dominates ferrous iron in amphiboles of the first kind, while ferrous iron largely preponderates in those of the second kind.

5. The $SiO_2 + TiO_2$ is equal to the MgO + FeO + CaO plus an amount sometimes equal to $4Na_2O$, but not always.

6. The ratio of $Fe_2O_3$ to CaO is quite variable.

*b*) For *soda-amphiboles* of various kinds, excepting that occurring in comendite.

1. The ratio of $Na_2O$ to CaO ranges from 1.23 to 4.6. That is, the lime is considerably less than the soda.

2. The ratio of $Al_2O_3$ to CaO ranges from 0.23 to 1.3.

3. The ratio of MgO + FeO to CaO ranges from 4.6 to 21.6, and the FeO is greatly in excess of MgO.

4. The variation in the $SiO_2$ indicates that $Na_2O$ is partly present in the riebeckite molecule, and partly replaces CaO and (Mg, Fe)O in the $RO \cdot SiO_2$ molecule.

*Micas* (*Table XIV*).—For these, as already said, the chemical component associated with $Al_2O_3$ which may be transferred from the feldspathic minerals is $K_2O$, and for purposes of calculation it is convenient to compare other components with $K_2O$. The micas included in Table XIV are of three kinds—biotite proper, lepidomelane, and phlogopite.

*a*) For *biotite:*

$Al_2O_3$ ranges from 1.3 to 1.9, and the ratio of $Fe_2O_3$ to $K_2O$ is 0.28 to 0.33, that is, nearly constant.

The ratio of $MgO + FeO$ to $K_2O$ is 4.5 to 5.9 and magnesia is in excess of ferrous iron. The ratio of MgO to FeO is 1.1 to to 1.6. Average, 1.5.

The $SiO_2$ nearly conforms to the theoretical molecule $(K, H)_2O \cdot (Al, Fe)_2O_3\ 2SiO_2 + n\ 2(Mg, Fe)O \cdot SiO_2$.

*b*) For *lepidomelane:*

The ratio of $Al_2O_3$ to $K_2O$ is nearly the same as in biotite, but that of $Fe_2O_3$ to $K_2O$ is higher in two cases.

$(Mg, Fe)O$ is lower, and ferrous iron dominates over magnesia.

*c*) For *phlogopite:*

The ratio of $Al_2O_3$ to $K_2O$ is nearly the same as for biotite and lepidomelane, but that of $Fe_2O_3$ to $K_2O$ is lower.

The ratio of $MgO + FeO$ to $K_2O$ is nearly the same as in biotite, but magnesia greatly predominates over ferrous iron.

The ratio of $SiO_2$ to $K_2O$, although nearly the same as in biotite, does not conform to the formula given for biotite.

From these relations we may deduce the following method of transferring aluminous molecules from salic and non-aluminous molecules from femic to form molecules of augite, amphibole, and mica.

*For the calculation of aluminous pyroxene:* The kind of pyroxene to be calculated should depend upon the kind of rock in which it occurs.

*a*) If the femic minerals already calculated for the rock include acmite molecules, sufficient $Na_2O$ and equal $Fe_2O_3$ are to be combined with diopside molecules to satisfy the ratio

$$\frac{Na_2O}{CaO} = D$$

(D standing for datum, the value given in the pyroxene or other mineral to be calculated); CaO in the ratio being equal to

$CaO_d$, in diopside, plus $CaO_{an}$, derived from anorthite, in consequence of the transfer of $Al_2O_3$ in sufficient amount to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d + CaO_{an}} = D .$$

Moreover, the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D ,$$

approximately 1, must be maintained by transferring (Mg,Fe)O from femic hypersthene or olivine. If the amount of these mineral is comparatively small a limit is set to the amount of aluminous pyroxene that can be produced.

*b*) If there are no acmite molecules estimated among the femic minerals, sufficient $Na_2O$ must be transferred from soda-feldspathic molecules to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D ,$$

where $\pm CaO_{an}$ is the lime transferred from, or to, anorthite. If transferred from anorthite to diopside the sign is $+$, if to anorthite from diopside the sign is $-$.

This follows from the fact that the transfer of $Na_2O$ from soda-feldspathic molecules liberates equal molecules of $Al_2O_3$, and if all of these are not needed to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D ,$$

as is the case in a number of pyroxenes given in Table XII, the $Al_2O_3$ not required withdraws CaO from diopside molecules to maintain the stoichiometric proportions obtaining in the salic minerals by making additional anorthite.

$Fe_2O_3$ is to be transferred from extra $Fe_2O_3$ (hematite) or from $FeO . Fe_2O_3$ (magnetite) in sufficient amount to satisfy the ratio.

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D .$$

The liberated FeO is to be added to sufficient (Mg, FeO) from hypersthene or olivine to maintain the ratio

$$\frac{(\mathrm{Mg,Fe})\mathrm{O}}{\mathrm{CaO_d} \pm \mathrm{CaO_{an}}} = \mathrm{D}\,.$$

When the sign of $CaO_{an}$ is — the transfer of (Mg,Fe)O and the liberated FeO is to hypersthene or olivine from diopside.

A readjustment of $SiO_2$ is necessary according as (Mg,Fe)O is transferred from or to hypersthene or olivine, and as $Na_2O$ is transferred from albite or nephelite. If there is extra $SiO_2$ it is placed first with the bases having strongest affinity for it unless these are already satisfied, when it appears as quartz.

In case the transfer is to be made to the complete exhaustion of one of the limiting components, the algebraic formulæ which can be devised for a particular case can be solved, but it frequently happens that augite occurs in rocks together with hypersthene or olivine, lime-soda-feldspars, and magnetite. The algebraic problem is indeterminable, since there are more unknown quantities than equations to satisfy them, unless the quantity of one or more of the minerals mentioned be given. More or less aluminous pyroxene within the limits of the magma appears to develop in different instances. The factors controlling the amount of augite crystallized in such cases are not at present known. The same statement may be made with reference to other aluminous ferromagnesian minerals.

*For the calculation of aluminous amphiboles: a*) *Hornblendes* contain more $Al_2O_3$ than $Na_2O$, and in the great majority of cases occur in rocks not having acmite molecules among the femic minerals.

To transform diopside molecules into those of hornblende sufficient $Na_2O$ must be transferred from soda-feldspars, and enough CaO from anorthite with their equivalent $Al_2O_3$ to satisfy the ratios

$$\frac{\mathrm{Na_2O}}{\mathrm{CaO_d} + \mathrm{CaO_{an}}} = \mathrm{D} \quad \text{and} \quad \frac{\mathrm{Al_2O_3}}{\mathrm{CaO_d} + \mathrm{CaO_{an}}} = \mathrm{D}\,.$$

Furthermore

$$\frac{Fe_2O_3}{CaO_d + CaO_{an}} = D$$

must be satisfied by transferring $Fe_2O_3$ from $Fe_2O_3$ (hematite), or from $FeO.Fe_2O_3$ (magnetite).

The liberated FeO with (Mg,Fe)O from hypersthene or olivine must be transferred to satisfy the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D\,.$$

$SiO_2$ must be adjusted in the manner already indicated for the case of pyroxene.

*b*) The calculation of the more alkalic amphiboles which occur in rocks rich in soda and iron and comparatively poor in lime and magnesia is to be made in the following manner:

Sufficient acmite molecules are transferred to satisfy the ratio

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D\,.$$

Equal $Na_2O$ from acmite plus sufficient $Na_2O$ from soda feldspars is transferred to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D\,.$$

$Al_2O_3$ equal to $Na_2O$ transferred from soda-feldspars is liberated and enough of it is transferred to amphibole to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D\,.$$

If all the liberated $Al_2O_3$ is not required to satisfy the last named ratio, CaO must be withdrawn from diopside to form additional anorthite, and the sign of $CaO_{an}$ is minus.

If more $Al_2O_3$ than that liberated from soda feldspars is needed to satisfy the ratio in question additional $Al_2O_3$ with CaO is transferred from anorthite, and the sign of CaO in the expression is plus.

The ratio

$$\frac{(Mg,Fe)O}{CaO_d \pm CaO_{an}} = D$$

must be established as well as that of

$$\frac{MgO}{FeO} = D$$

since the latter is highly characteristic.

The adjustment of $SiO_2$ follows the ratio

$$\frac{SiO_2}{CaO_d \pm CaO_{an}} = D$$

and the requirements of the other molecules.

*For the calculation of ferromagnesian mica.*—The process is essentially the same for various kinds, the values of the ratios varying for biotite, lepidomelane, and phlogopite.

In most cases $Al_2O_3$ is in excess of $K_2O$, and in transferring $K_2O$ from feldspathic molecules the accompanying equal $Al_2O_3$ is not sufficient to satisfy the ratio

$$\frac{Al_2O_3}{K_2O} = D\,.$$

Extra $Al_2O_3$ may be derived from corundum when estimated present, and this will be the case in numerous rocks in which muscovite and biotite have developed.

If there is no extra $Al_2O_3$ of this kind, $Al_2O_3$ must be transferred from anorthite until the ratio in question is satisfied. The liberated CaO must be transferred to diopside molecules.

$Fe_2O_3$ is to be transferred from $Fe_2O_3$ (hematite) or FeO. $Fe_2O_3$ (magnetite), and the liberated FeO is to be added to (Mg,Fe)O, to satisfy the ratio

$$\frac{Fe_2O_3}{K_2O} = D\,.$$

(MgFe)O must be transferred from hypersthene or olivine to satisfy the ratio

$$\frac{(Mg,Fe)O}{K_2O} = D\,,$$

and the ratio $\frac{MgO}{FeO}$ must be maintained according to the kind of mica.

$SiO_2$ and $TiO_2$ are to be transferred according to their respective ratios

$$\frac{SiO_2}{K_2O} = D \quad \text{and} \quad \frac{TiO_2}{K_2O} = D .$$

After which $SiO_2$ must be adjusted among the molecules affected. In general some $SiO_2$ will be liberated and the amount of quartz in quartz-bearing rocks will be increased. In other cases lower silicates will be raised.

The calculation of muscovite is simple, for the reason that it occurs mainly in rocks in which there is an excess of $Al_2O_3$, estimated as corundum.

Since in common muscovite $H = 2K$ the following ratios obtain:

$$\frac{H_2O}{K_2O} = 2 , \quad \frac{Al_2O_3}{K_2O} = 3 , \quad \frac{SiO_2}{K_2O} = 6 .$$

Such a muscovite equals orthoclase plus corundum plus water.

$$2H_2O + K_2O + 3Al_2O_3 + 6SiO_2 = K_2O + Al_2O_3 + 6SiO_2 + 2Al_2O_3 + 2H_2O .$$

Hence to the molecules of hypothetical corundum add half as many of the orthoclase and an equal number of $H_2O$. The distribution of $SiO_2$ remains as before, the amount of quartz has not been affected.

From the foregoing it is seen that the development of augite in rocks reduces the amount of anorthite molecules calculated among the salic minerals and also reduces the amount of hypersthene or olivine that appear as femic. It affects the distribution of silica by liberating a part of that allotted to anorthite when the (Mg,Fe)O is derived from hypersthene, or when $Na_2O$ is transferred from albite molecules. Its development would reduce the amount of olivine rather than hypersthene when both are otherwise normatively present.

The crystallization of hornblende reduces the amount of anorthite and hypersthene or olivine reckoned as standard minerals at a greater rate than that of augite would, in proportion to the amount of femic diopside molecules converted into hornblende, because the ratio of $Al_2O_3$ to CaO is higher, and the ratio of (Mg,Fe)O to CaO is twice as great as in augite. The effect on the $SiO_2$ would be similar.

The reduction of anorthite molecules by both these processes would affect the character of the plagioclase actually developed in the rock as compared with that reckoned as standard.

The development of mica would reduce the molecules of potash feldspar or of leucite, and the formation of biotite would also reduce the amount of hypersthene or olivine, and that of magnetite. It would reduce the amount of calculated corundum, or, in the absence of this extra $Al_2O_3$, would reduce the molecules of anorthite and increase those of diopside or wollastonite. The distribution of $SiO_2$ would be affected, and in cases where there is no extra $Al_2O_3$ and where (Mg,Fe)O is derived from hypersthene $SiO_2$ would be liberated to raise lower to higher silicates, or to form quartz.

*Garnet.*—In the matter of garnet it is easily seen that to form simple lime-alumina garnet (grossularite), $3CaO.Al_2O_3.3SiO_2$, it is necessary to combine anorthite molecules with femic wollastonite, $CaO.SiO_2$, with the liberation of silica. And it will be found that this garnet is frequently developed in rocks whose estimated standard minerals include wollastonite, and its crystallization reduces the amount of anorthite.

## AN EXAMPLE OF CALCULATION.

As an illustration of the several processes above described we present the case of the Butte granite, because of its fairly uniform composition as shown by five analyses,[1] its distinct crystallization, which is of such size as to permit of accurate microscopical measurement, and because the two aluminous ferromagnesian minerals, biotite and hornblende, have been separated and analyzed. The rock from which these minerals

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[1] WEED, W. H., JOUR. GEOL., p. 739, 1899.

were separated has been analyzed, and this analysis forms the basis for the calculation of the standard mineral composition. It is from Walkerville Station, near Butte, Mont. The thin section measured is from a specimen of very fresh rock taken near the surface twenty feet from the outcrop of the Parrot vein at Butte.

TABLE VII.

| | | Mol. | Pyr. | Ilm. | Ap. | Mag. | Orth. | Alb. | An. | Diop. | Hyp. | Qu'tz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$..... | 63.88 | 1.065 | .. | .. | .. | .. | 270 | 270 | 130 | 6 | 64 | 323 |
| $Al_2O_3$... | 15.84 | .155 | .. | .. | .. | .. | 45 | 45 | 65 | .. | .. | .. |
| $Fe_2O_3$... | 2.11 | .013 | .. | .. | .. | 13 | .. | .. | .. | | .. | .. |
| FeO..... | 2.59 | .036 | 2 | 8 | .. | 13 | .. | .. | .. | 3 | 63 | .. |
| MgO..... | 2.13 | .053 | .. | .. | .. | .. | .. | .. | .. | | .. | .. |
| CaO..... | 3.97 | .071 | .. | .. | 3 | .. | .. | .. | 65 | 3 | .. | .. |
| $Na_2O$.... | 2.81 | .045 | .. | .. | .. | .. | .. | 45 | .. | .. | .. | .. |
| $K_2O$..... | 4.23 | .045 | .. | .. | .. | .. | 45 | .. | .. | .. | .. | .. |
| $H_2O+$... | .66 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $H_2O-$... | .22 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $TiO_2$..... | .65 | .008 | .. | 8 | .. | .. | .. | .. | .. | .. | .. | .. |
| $P_2O_5$.... | .21 | .001 | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. |
| MnO..... | .07 | .001 | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. |
| SrO...... | .02 | .000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| BaO..... | .09 | .000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $Li_2O$..... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $SO_3$..... | .34 | .004 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Cl....... | tr | .... | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | 99.82 | | | | | | | | | | | |

| FORMULA. | MOL. WT. | | NORM. | | |
|---|---|---|---|---|---|
| $SiO_2$ | 323 × 60 | quartz | 19.36 | Q | 19.38 |
| $K_2O.Al_2O_3.6SiO_2$ | 45 × 556 | orthoclase | 25.02 | F | 66.67 |
| $Na_2O.Al_2O_3.6SiO_2$ | 45 × 524 | albite | 23.58 | | |
| $CaO.Al_2O_3.2SiO_2$ | 65 × 278 | anorthite | 18.07 | | |
| $CaO.SiO_2$ | 3 × 116 | diopside | .67 | P | 7.45 |
| $MgO.SiO_2$ | 2 × 100 | | | | |
| $FeO.SiO_2$ | 1 × 132 | | | | |
| $MgO.SiO_2$ | 51 × 100 | hypersthene | 6.78 | | |
| $FeO.SiO_2$ | 13 × 132 | | | | |
| $FeO.Fe_2O_3$ | 13 × 232 | magnetite | 3.01 | M | 4.24 |
| $FeO.TiO_2$ | 8 × 152 | ilmenite | 1.22 | | |
| $FeS_2$ | 2 × 120 | pyrite | .24 | A | .55 |
| $3CaO.P_2O_5$ | 1 × 310 | apatite | .31 | | |
| | | etc. | .99 | | |
| | | | 99.27 | | |

*a*) *The calculation of the standard minerals, or norm*, is expressed in Table VII. MnO is combined with FeO making 0.037 molecules. $SO_3$ is allotted to FeO to form $FeS_2$ because of the pyrite known to be present in the rock, $TiO_2$ to ilmenite, $P_2O_5$ to apatite, $Fe_2O_3$ to magnetite, $K_2O$ to orthoclase, $Na_2O$ to albite, the remaining $Al_2O_3$ (0.065 mol.) to anorthite, the remaining

CaO to diopside, the remaining (Mg,Fe)O to hypersthene, and the remaining $SiO_2$ to quartz. From the respective molecules the percentage weights are found by multiplying each by the molecular weight.

The classification of this rock from the data given in Table VII has been described on a previous page (177) as an example of an intermediate rock.

*b*) *To calculate the mode* from the chemical analysis of the rock we have to introduce biotite and hornblende into the calculation, and we have the chemical analysis of each given in Tables XIII and XIV. We will assume that they contain all the magnesia (MgO) and all the iron oxide (FeO and $Fe_2O_3$), except that which goes into pyrite, magnetite and ilmenite. For these are the only ferromagnesian minerals observed in thin sections of the rock except a small amount of pyroxene intergrown with the hornblende. This was probably included in the hornblende material analyzed so that the analysis represents the mixture and may for the present calculation be treated as the composition of one mineral.

In Tables XIII and XIV are found the following ratios:

For *Butte hornblende:*

$$\frac{MgO}{CaO}=1.53\,,\quad \frac{FeO}{CaO}=.71\,,\quad \frac{Al_2O_3}{CaO}=.32\,,\quad \frac{Fe_2O_3}{CaO}=.15\,,$$

$$\frac{Na_2O}{CaO}=.12\,,\quad \frac{SiO_2}{CaO}=3.79\,.$$

For *Butte biotite:*

$$\frac{MgO}{K_2O}=3.12\,,\quad \frac{FeO}{K_2O}=1.96\,,\quad \frac{Al_2O_3}{K_2O}=1.3\,,\quad \frac{Fe_2O_3}{K_2O}=.32\,,$$

$$\frac{H_2O}{K_2O}=.7\,,\quad \frac{SiO_2}{K_2O}=.6\,,\quad \frac{TiO_2}{K_2O}=.44\,.$$

If $x$=molecules of CaO in hornblende, $y$=molecules of $K_2O$ in biotite, $z$=molecules of $Fe_2O_3$ in resulting magnetite, $w$= molecules of $TiO_2$ in resulting ilmenite,

$$\begin{aligned}
\text{Then } 2.24x+5.08y+z+w &= 88=\text{(Total (Mg,Fe)O less FeO in pyrite)}.\\
.15x+.32y+z &= 13=\text{(Total } Fe_2O_3\text{)}.\\
.44y+w &= 8=\text{(Total } TiO_2\text{)}.\\
.32x+1.3\,y &= 12x+y+(x-3)=\text{(transferred } Al^2O_3\text{)}.
\end{aligned}$$

That is, the $Al_2O_3$ in hornblende and biotite equals the transferred soda, potash and transferred lime, which latter equals the CaO in hornblende less that previously allotted to dioside $(x-3)$. From these equations are derived the following values:

$$x = 8.4\ (8)\ ,\quad y = 12.4\ (12)\ ,\quad z = 7.8\ (8),\quad w = 2.5\ (3)\ .$$

From these values of $x, y, z$ and $w$ the readjustments for all the minerals are made as indicated in Table VIII.

TABLE VIII.

| | Mol. | Pyr. | Ilm. | Mag. | Ap. | Orth. | Alb. | An. | Biot. | Horn. | Quartz. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ .... | 1.065 | . | . | . | . | 198 | 264 | 120 | 72 | 30 | 381 |
| $Al_2O_3$ ... | .155 | . | . | . | . | 33 | 44 | 60 | 16 | 2 | ... |
| $Fe_2O_3$ ... | .013 | . | . | 8 | . | ... | ... | ... | 4 | 1 | ... |
| FeO ..... | .036 | 2 | 3 | 8 | . | ... | ... | ... | 19 | 4 | ... |
| MgO .... | .053 | . | . | . | . | ... | ... | ... | 41 | 12 | ... |
| CaO ..... | .071 | . | . | . | 3 | ... | ... | 60 | .. | 8 | ... |
| $Na_2C$ .... | .045 | . | . | . | . | ... | 44 | ... | .. | 1 | ... |
| $K_2O$ ..... | .045 | . | . | . | . | 33 | ... | ... | 12 | .. | ... |
| $H_2O+$ ... | ..... | . | . | . | . | ... | ... | ... | 8 | .. | ... |
| $H_2O-$ ... | ..... | . | . | . | . | ... | ... | ... | .. | .. | ... |
| $TiO_2$ .... | .008 | . | 3 | . | . | ... | ... | ... | 5 | .. | ... |
| $P_2O_5$ .... | .001 | . | . | . | 1 | ... | ... | ... | .. | .. | ... |
| MnO .... | .001 | . | . | . | . | ... | .. | ... | .. | 1 | ... |
| $SO_3$ ..... | .004 | 4 | . | . | . | ... | ... | ... | .. | .. | ... |
| Etc. ..... | ..... | . | . | . | . | ... | ... | ... | ... | ... | ... |

$x = 8 =$ mol. CaO in hornblende.
$y = 12 =$ mol. $K_2O$ in biotite.
$z = 8 =$ mol. $Fe_2O_3$ in magnetite.
$w = 3 =$ mol. $TiO_2$ in ilmenite.

| FORMULA. | MOL WT. | | MODE. |
|---|---|---|---|
| $SiO_2$ | 381 × 60 | = quartz | 22.86 |
| $K_2O.Al_2O_3.6SiO_2$ | 33 × 556 | = orthoclase | 18.35 |
| $Na_2O.Al_2O_3.6SiO_2$ | 44 × 524 | = albite | 23.06 |
| $CaO.Al_2O_3.2SiO_2$ | 60 × 278 | = anorthite | 16.68 |
| $8H_2O$ | 8 × 18 | = biotite | 10.92 |
| $12K_2O$ | 12 × 94 | | |
| $16Al_2O_3$ | 16 × 102 | | |
| $4Fe_2O_3$ | 4 × 160 | | |
| $41MgO$ | 41 × 40 | | |
| $19FeO$ | 19 × 72 | | |
| $5TiO_2$ | 5 × 80 | | |
| $72SiO_2$ | 72 × 60 | | |
| $1Na_2O$ | 1 × 62 | = hornblende = | 3.56 |
| $8CaO$ | 8 × 56 | | |
| $12MgO$ | 12 × 40 | | |
| $5FeO$ | 5 × 72 | | |
| $2Al_2O_3$ | 2 × 102 | | |
| $1FeO_3$ | 1 × 160 | | |
| $30SiO_2$ | 30 × 60 | | |
| $FeO.Fe_2O_3$ | 8 × 232 | = magnetite = | 1.86 |
| $FeO.TiO_2$ | 3 × 152 | = ilmenite = | .46 |
| $FeS_2$ | 2 × 120 | = pyrite = | .24 |
| $3CaO.P_2O_5$ | 1 × 310 | = apatite = | .31 |
| | | etc. | .85 |
| | | | 99.15 |

*c*) *The process of calculating the norm from the mode*, that is, the standard mineral composition from a microscopical investigation of rock sections, may be illustrated as follows :

Two thin sections of Butte granite were examined ; one from a surface excavation, twenty feet from the Parrott vein, very fresh, with almost no signs of alteration, the other from similar rock used in building in the city of Butte, the location of the quarry not noted.

In the first section an aggregate distance of 12,740 units of the micrometer scale was measured, embracing 604 measurements. The average diameter of the plagioclase crystals was 32 units, and the total length of plagioclase diameters was 5,492. Table IX shows the lengths, relative volumes, assumed specific gravities of each mineral, and the resulting percentages by weight.

TABLE IX.

| | First Rock. | | | | Second Rock. | |
|---|---|---|---|---|---|---|
| | Total Diameters. | Relative Volumes. | Sp. gr. | Weights. | Relative Volumes. | Weights. |
| Quartz | 2,954 | 23.17 | 2.65 | 22.55 | 20.97 | 20.34 |
| Orthoclase | 2,373 | 18.62 | 2.57 | 17.57 | 21.07 | 19.82 |
| Plagioclase | 5,492 | 43.10 | 2.68 | 42.47 | 42.29 | 41.48 |
| Biotite | 1,130 | 8.87 | 3.00 | 9.77 | 8.15 | 8.94 |
| Hornblende | 482 | 3.78 | 3.20 | 4.44 | 4.84 | 5.67 |
| Pyroxene | 252 | 1.97 | 3.30 | 2.37 | 2.07 | 2.50 |
| Magnetite | 51 | .40 | 5.17 | .76 | .54 | 1.02 |
| Pyrite | 6 | .04 | 5.00 | .07 | .02 | .04 |
| | 12,740 | 99.95 | | 99.98 | 99.95 | 99.81 |

In the second rock section examined an aggregate distance of 7,122 units of the scale was measured, embracing 403 measurements. The average diameter of the plagioclase was 24 units, and the total length of plagioclase diameters was 3,012. The relative volumes and weights are given in the last two columns of the Table.

A comparison of the two cases shows how closely the rocks resemble one another, the second being slightly higher in orthoclase and lower in quartz than the first. Other sections from

Butte granite from other localities in the vicinity of Butte show slightly more ferromagnesian minerals. Weed[1] has called attention to the generally uniform composition of this great body of granite as indicated by five chemical analyses, one of which is given in the tables of mica and hornblende. The specimen from near the Parrot vein will be made the basis of the following discussion.

Optical investigation of the plagioclase by the Michel-Lévy method with Carlsbad twins of albite twins showed that the central portion of each crystal has approximately the composition of Ab$_1$An$_1$, but the marginal zones are more sodic, having in some crystals the composition of oligoclase as indicated by the optical orientation and the relative index of refraction as compared with quartz by the Becke method. Without making the necessary observations for estimating the relative proportions of the several zones, and the average composition of the plagioclase as a whole, it was seen that the greater part of each crystal is about Ab$_1$ An$_1$, and only a narrow margin is oligoclase, but the optical orientation of .the outer portions shifts gradually in most cases from the central part to the margin. The average composition of the plagioclase is probably andesine somewhat more sodic than Ab$_1$ An$_1$. If Ab$_3$An$_2$, it would have the composition of the mixture of albite and anorthite calculated from the chemical analysis of the Butte granite from Walkerville Station already cited, after developing biotite and hornblende. In this case the 42.47 per cent. of plagioclase would yield by molecular calculation 24.71 per cent. albite and 17.76 per cent. anorthite. In the second rock there would be 24.29 per cent. albite and 17.18 per cent. anorthite. The orthoclase may be considered as wholly potassic and reckoned as pure orthoclase.

In order to obtain the salic and femic components of the biotite, hornblende, and pyroxene, since the other minerals are standard, we may take the analysis of Butte biotite from Table XIV and multiply it by 0.0977, the percentage weight of biotite, and take the analysis of Butte hornblende from Table XIII and multiply it by 0.0681, the combined percentage weight of hornblende and

[1] WEED, W. H., JOUR. GEOL., Vol. VII, pp. 737–50.

pyroxene, for the reason already given. The resulting constituents reduced to molecular proportions may be distributed among salic and femic minerals as shown in the accompanying Table X.

From these data we deduce the standard mineral composition of the rock from near the Parrot vein as follows:

TABLE X.

| | 9.77 % Biot. | 6.81% Hornbl. | Sum. | Fluor. | Ilm. | Mag. | Orth. | Alb. | An. | Diop. | Hyp. | Minus Qu'rtz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ...... | 3.58 | 3.11 | .111 | .. | .. | .. | 66 | 6 | 12 | 12 | 64 | —49 |
| $Al_2O_3$ ..... | 1.37 | .46 | .018 | .. | .. | .. | 11 | 1 | 6 | .. | .. | .... |
| $Fe_2O_3$ ..... | .52 | .34 | .005 | .. | .. | 5 | .. | .. | .. | .. | .. | .... |
| FeO ....... | 1.37 | .71 | .029 | .. | 6 | 5 | .. | .. | .. | 2 | 16 | .... |
| MgO ...... | 1.21 | .82 | .051 | .. | .. | .. | .. | .. | .. | 4 | 47 | .... |
| CaO ....... | .00 | .76 | .014 | 2 | .. | .. | .. | .. | 6 | 6 | .. | .... |
| $Na_2O$ ..... | .01 | .05 | .001 | .. | .. | .. | .. | 1 | .. | .. | .. | .... |
| $K_2O$ ...... | .91 | .08 | .011 | .. | .. | .. | 11 | .. | .. | .. | .. | .... |
| $H_2O-$ .... | .12 | .03 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .... |
| $H_2O+$ .... | .36 | .16 | .... | .. | .. | .. | .. | .. | .. | .. | .. | .... |
| $TiO_2$ ...... | .35 | .10 | .006 | .. | 6 | .. | .. | .. | .. | .. | .. | .... |
| $P_2O_5$ ...... | .01 | .02 | .000 | .. | .. | .. | .. | .. | .. | .. | .. | .... |
| MnO ...... | .02 | .04 | .001 | .. | .. | .. | .. | .. | .. | .. | 1 | .... |
| BaO ....... | .01 | .... | .... | .. | .. | .. | .. | .. | .. | .. | .. | .... |
| Cl ......... | .02 | .... | .... | .. | .. | .. | .. | .. | .. | .. | .. | .... |
| F ......... | .07 | .02 | .004 | 4 | .. | .. | .. | .. | .. | .. | .. | .... |

| FORMULA. | MOL. WT. | | |
|---|---|---|---|
| $SiO_2$ | $49 \times 60$ | = quartz = | 2.94 |
| $K_2O.Al_2O_3.6SiO_2$ | $11 \times 556$ | = orthoclase = | 6.12 |
| $Na_2O.Al_2O_3.6SiO_2$ | $1 \times 524$ | = albite = | .52 |
| $CaO.Al_2O_3.2SiO_2$ | $6 \times 278$ | = anorthite = | 1.67 |
| $CaO.SiO_2$ | $6 \times 116$ | = diopside = | 1.36 |
| $MgO.SiO_2$ | $4 \times 100$ | | |
| $FeO.SiO_2$ | $2 \times 132$ | | |
| $MgO.SiO_2$ | $47 \times 100$ | = hypersthene = | 6.94 |
| $FeO.SiO_2$ | $17 \times 132$ | | |
| $FeO.Fe_2O_3$ | $5 \times 232$ | = magnetite = | 1.16 |
| $FeO.TiO_2$ | $6 \times 152$ | = ilmenite = | .91 |
| $CaF_2$ | $2 \times 94$ | = fluorite = | .19 |

| Percentages Determined from Rock. | | Readjustments. | | Standard Mineral Composition. | |
|---|---|---|---|---|---|
| Quartz............. | 22.55 | ............... | —2.94 | Quartz.......... | 19.61 |
| Orthoclase......... | 17.57 | ............... | +6.12 | Orthoclase....... | 23.69 |
| Plagioclase. ....... | 42.47 | Albite 24.71.... | + .52 | Albite........... | 25.23 |
| | | Anorthite 17.76. | +1.67 | Anorthite........ | 19.43 |
| Biotite ............ | 9.77 | Diopside....... | 1.36 | Diopside........ | 1.36 |
| Hornblende ....... | 4.44 | Hypersthene.... | 6.94 | Hypersthene..... | 6.94 |
| Pyroxene.......... | 2.37 | Fluorite........ | .19 | Fluorite......... | .19 |
| | | Ilmenite........ | .91 | Ilmenite......... | .91 |
| Magnetite ......... | .76 | ............... | +1.16 | Magnetite....... | 1.92 |
| Pyrite............. | .07 | | | Pyrite.......... | .07 |
| | | | | | 99.35 |

The approximate chemical composition of this rock is found by separating each of the minerals observed in the rock into its chemical components. The results are given below:

TABLE XI.

| | Biotite. | Hornblende and Pyroxene. | Magnetite. | Pyrite. | Anorthite. | Albite. | Orthoclase. | Quartz. | First Rock. | Second Rock. | Atlantic Mine. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ... | 3.58 | 3.11 | ... | ... | 7.66 | 16.97 | 11.37 | 22.55 | 65.24 | 64.43 | 64.34 |
| $Al_2O_3$ .. | 1.37 | .46 | ... | ... | 6.52 | 4.81 | 3.22 | ..... | 16.38 | 16.46 | 15.72 |
| $Fe_2O_3$ .. | .52 | .34 | .52 | ... | .... | ..... | ..... | ..... | 1.38 | 1.57 | 1.62 |
| FeO.... | 1.37 | .71 | .22 | .04 | .... | ..... | ..... | ..... | 2.35 | 2.42 | 2.94 |
| MgO... | 1.21 | .82 | ... | ... | .... | ..... | ..... | ..... | 1.93 | 2.10 | 2.17 |
| CaO.... | .00 | .76 | ... | ... | 3.57 | ..... | ..... | ..... | 4.33 | 4.38 | 4.24 |
| $Na_2O$... | .01 | .05 | ... | ... | .... | 2.93 | ..... | ..... | 2.99 | 2.95 | 2.76 |
| $K_2O$ ... | .91 | .08 | ... | ... | .... | ..... | 2.97 | ..... | 3.96 | 4.27 | 4.04 |
| $H_2O-$. | .12 | .03 | ... | ... | .... | ..... | ..... | ..... | .15 | .15 | .25 |
| $H_2O+$. | .36 | .16 | ... | ... | .... | ..... | ..... | ..... | .52 | .43 | .76 |
| $TiO_2$... | .35 | .10 | ... | ... | .... | ..... | ..... | ..... | .45 | .35 | .53 |
| $P_2O_5$... | .01 | .02 | ... | ... | .... | ..... | ..... | ..... | .03 | .04 | .14 |
| MnO... | .02 | .04 | ... | ... | .... | ..... | ..... | ..... | .06 | .06 | .12 |
| SrO.... | ... | .... | ... | ... | .... | ..... | ..... | ..... | ... | ... | .03 |
| BaO.... | .01 | .... | ... | ... | .... | ..... | ..... | ..... | .01 | .01 | .06 |
| Cl...... | .02 | .... | ... | ... | .... | ..... | ..... | ..... | .02 | .02 | .03[1] |
| F..... | .07 | .02 | ... | ... | .... | ..... | ..... | ..... | .09 | .09 | .005[2] |
| S...... | .... | .... | ... | .04 | .... | ..... | ..... | ..... | .04 | .02 | .03[3] |
| ....... | .... | .... | ... | ... | .... | ..... | ..... | ..... | ..... | ..... | .02[4] |
| | | | | | | | | | 99.93 | 99.75 | 99.805 |

[1] $CO_2$ [2] Cu [3] $FeS_2$ [4] $ZrO_2$

The chemical composition of the second rock from Butte in which the minerals were measured is given in the same table, and also the analysis of Butte granite from the Atlantic Mine. The similarity of the results is an indication of the success of the process in this instance.

With the data here assembled it is possible to classify the rock from near the Parrot vein with almost as much accuracy as though it had been analyzed chemically. In other cases the data may not be so nearly correct, but the error in many cases will be quite within the limits of variation for the division of the classification to which the rock belongs.

It is evident that there is need for more chemical work upon the component minerals of igneous rocks and the correlation of their optical properties and chemical composition with that of the rocks containing them. The necessity is also apparent for complete analyses not only as to the main constituents, but also as regards some of the constituents hitherto considered as rare or of little importance, but which modern investigation has shown to be widely distributed and often of considerable influence on the norm and mode. The constituents present usually in small amounts are distributed very unequally among the various kinds of rock magmas, and it would save the careful analyst much needless labor if the petrographer would indicate to him those which it is advisable to look for and determine.

# EPILOGUE.

Some who read this essay will, without doubt, object to the method of classification herein proposed because it is new and embodies new principles, since experience has shown that one's mental attitude toward new methods is on the whole conservative, and tends to resist their introduction. It is, also, easier to travel along a familiar and oft-trodden path, no matter how crooked and obstructed it may be, than to hew out a new one and provide a broader way for the future.

Objection will doubtless be made that the system, on account of the definite quantitative character of its divisions, throws a greater amount of mental responsibility in classifying upon the one who uses it. Thus, for instance, at the very outset, it will often happen that megascopically a rock will be so close to one of the lines separating two different classes that it will be difficult to know to which one it should be assigned. And it will sometimes happen that later chemical or microscopical investigation will show the preliminary classification to have been wrongly made. Moreover, when such examinations have been made, it will often occur that it is largely a matter of judgment as to which of two adjacent Orders, Rangs, or Grads a rock properly belongs.

To some this mental responsibility is distasteful and unsatisfactory; they desire a classification made up of a number of simple divisions like neat pigeon-holes or compartments into which each object can be easily and promptly thrust and docketed, and any method which fails to achieve this and relieve them of considerable mental effort in classifying rocks will not, in their estimation, be a proper one.

Unfortunately the difficulty in this respect lies not in the method, but is inherent in the subject itself. Rocks grade into one another in all directions, chemically, minerally, and texturally, and these again overlap in the different modes of geological occurrence.

Therefore, unless the future should reveal new properties of rocks, as yet unknown and unsuspected, which may be used as bases of classification, every method so far devised, or which can be devised, must have artificial lines of division, and cause the petrographer trouble in certain cases in deciding where his rocks belong. The erection of the monzonite group by Brögger is a good example of this. Where rocks contained about equal amounts of orthoclase and plagioclase it was formerly difficult to say whether they should be classed as syenites or diorites. The formation of the monzonite group avoided this difficulty. but in its turn gave rise to two others whose sum total is greater than the original one; for it is clear that it will be equally difficult now to decide whether a syenite with considerable plagioclase is still a syenite or a monzonite, and the same difficulty is met in diorites with considerable orthoclase. Thus, the formation of new groups simply multiplies the difficulty; it does not remove it.

The system which we propose does not, therefore, meet this trouble; it does not pretend to, for any system based on our present knowledge of rocks which should claim this would be in the nature of a mere nostrum, and would simply profess to do what it could not perform. In the ultimate analysis, every system will and must throw on the petrographer the mental responsibility of deciding, in a considerable number of cases, where rocks lie close upon divisional lines, into which of two divisions they must be put. He may not like this, but it cannot be avoided.

In different systems this difficulty is met in greater or lesser degree in different parts of the systems. In the one we propose it occurs chiefly in doubtful cases, at the beginning, and in the sum total we believe that it is less, or at all events no greater, than in any system heretofore proposed. But in regard to this each must judge for himself.

Objection may also be raised to this method of classification, that it entails a greater amount of labor upon the petrographer than those now in use. Perhaps there are some who, recalling the possibility of glancing through a microscope and noticing the presence of striated feldpars, with one or more dark-colored minerals, and promptly identifying the rock, regret the introduction of the chemical character of the feldspars and the quantitative determination of all the minerals. But to such we have no apology to make. Already precise optical methods of determining the feldspars are in use; and the confusion resulting from an absence of the quantitative element in rock definitions is becoming intolerable. The time has come when the petrographer should demand the exactness and sharpness of definition which, though obtained only by patient and careful work, add clearness to the conceptions and proportionate weight to the results of petrographic investigation.

It may be thought that the method of obtaining the approximate chemical composition of the magma by optical study and computation of the minerals in a rock is tedious, as it might possibly take several hours of work. But let one who considers this seriously make a good, careful, and accurate chemical analysis and note the amount of time consumed. We urge him not to throw the task on someone else, especially not on some beginner in analytical chemistry, as has unfortunately so often happened, but to make the analysis himself. Indeed, every petrographer should have made enough analyses to properly appreciate what they mean, after which we feel sure he will not object to the length of time involved in a microscopical analysis when one is possible.

Again, we have assumed as a condition for proper and convenient classification that it should be dichotomous, since not more than two factors can be handled advantageously at one time. To those who may not agree with this proposition we can only recommend the trial of forming a classification, using three or more factors at once. We have been through this phase of belief most thoroughly, and have convinced ourselves that two factors are all that can be handled at once without complications which would destroy the practical usefulness of any system. We believe that anyone who tries it will come to the same conclusion.

Furthermore, repeated trials have led us to think that a fivefold division is the most practicable one and the one best suited for the needs of petrography. We have applied this logically throughout, except in certain cases where a threefold seemed sufficient.

We desire also to ask the reader to bear in mind that the scheme of classification and nomenclature herein proposed is of much greater importance in some features than in others. The important points to bear in mind, and on which our system rests, are these:

*a*) The bringing together of rocks of *similar chemical composition* into the same divisions.

*b*) The resolution of a rock, either from its chemical or microscopical analysis, into quantitative amounts of certain *standard* minerals.

*c*) The establishment of a strictly *quantitative* basis of comparison of rock constituents, so that all constituents are valued according to their proportions.

*d*) The division of the minerals into two main groups, *salic* and *femic*, thus obtaining two factors, and the application of the fivefold division.

*e*) The recognition of the relation of the *mode* to the *norm*.

Time, use, and experience, if this system gains the currency we hope for it, may cause modifications in the smaller divisions; and the suggestions we have made in regard to nomenclature, both of rocks and of descriptive terms for their textures, may only in part be followed. But these are minor features and their importance is relatively small compared with the main points enumerated above. It is upon them that the system rests, and upon their adoption or rejection that it must either stand or fall.

The petrographer who believes that these fundamental points are correct and who is willing to accept them will not wish to reject the whole system because he may not agree with some of its minor features, but the one who does not accept the fundamental points will have no use for this system, or any of its features, great or small.

At first it will not be easy for the petrographer to think of rocks as expressed in this system ; it will require some use and experience. Nearly everywhere over the whole field it introduces new conceptions, and we firmly believe more correct and logical ones than have hitherto prevailed. We have made no attempt to modify, or patch up, or define the older previous systems, for we believe that the day for efforts of that kind has passed; that they have had their use and should now be replaced by something more in accord with the results of the great amount of recent investigations, and of our present knowledge, and therefore better adapted to present and future needs. It is of course easier to patch and wear old garments than to make new ones, but to confess this fact as controlling one's attitude toward new propositions would be merely to acknowledge a condition of mental supineness.

If petrographers believe this system to be an advance over previous ones, we offer no apology for imposing a new mental burden upon them, for it is obvious that the ever-increasing accumulation of knowledge of the chemical and mineral properties of rocks, and of their relations to one another and to their texture, mode of occurrence, and their origin impose a greater task on modern petrographers than was borne by those of a former generation. And since it is not to be assumed that the present state of petrographical knowledge is complete, provision should be made for expansion and adjustment along lines which seem to be those in which future development will take place.

# TABLES TO AID THE CALCULATION OF NORMS AND MODES OF IGNEOUS ROCKS.

THE accompanying tables have been prepared to facilitate the calculation of the mineral composition of igneous rocks from chemical analyses of the rocks. The first group of tables presents the molecular proportions of the principal chemical components of rocks. These have been obtained by dividing percentage weights by molecular weights. The components are those in which chemical analyses of rocks and minerals are usually expressed; for the most part oxides of the bases present. The second group of tables furnishes the percentage weights of the standard minerals, or of the simpler mineral molecules. They have been obtained by multiplying the number of mineral molecules by their molecular weights.

In several cases the calculations are so simple that no tables have been prepared, it being more of an undertaking to look up the results in tables than to calculate them. This applies to silica ($SiO_2$) with molecular weight, 60; magnesia ($MgO$) molecular weight, 40; magnesium meta-silicate ($MgO.SiO_2$) and calcium carbonate ($CaO.CO_2$) with the molecular weight in each case 100.

It is important to note the unit of calculation in the tables of percentage weights. ".001 Mol." represents the relative proportion of a mineral molecule as expressed by the dualistic formula above each table. In some cases the number of mineral molecules is the same as that of the oxide of the basic metal in the mineral. Thus the number of molecules of orthoclase is the same as those of $K_2O$ in it. But in magnesium and iron orthosilicate the number of molecules of each compound is one-half that of $MgO$ or $FeO$. It is the same as that of $SiO_2$. In akermanite the number of mineral molecules is one-fourth that of $CaO$.

## MOLECULAR PROPORTIONS OF CHEMICAL COMPONENTS OF ROCKS.

### SILICA, $SiO_2$ MOLECULAR WEIGHT, 60.

Divide Percentage Weight by 60.

### ALUMINA, $Al_2O_3$. MOLECULAR WEIGHT, 102.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | 0 |
| 1 | .010 | .011 | .012 | .013 | .014 | .015 | .016 | .017 | .018 | .019 | 1 |
| 2 | .020 | .021 | .022 | .023 | .024 | .025 | .025 | .026 | .027 | .028 | 2 |
| 3 | .029 | .030 | .031 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | 3 |
| 4 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .046 | .047 | .048 | 4 |
| 5 | .049 | .050 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | 5 |
| 6 | .059 | .060 | .061 | .062 | .063 | .064 | .065 | .066 | .067 | .068 | 6 |
| 7 | .069 | .070 | .071 | .072 | .073 | .074 | .075 | .075 | .076 | .077 | 7 |
| 8 | .078 | .079 | .080 | .081 | .082 | .083 | .084 | .085 | .086 | .087 | 8 |
| 9 | .088 | .089 | .090 | .091 | .092 | .093 | .094 | .095 | .096 | .097 | 9 |
| 10 | .098 | .099 | .100 | .101 | .102 | .103 | .104 | .105 | .106 | .107 | 10 |
| 11 | .108 | .109 | .110 | .111 | .112 | .113 | .114 | .115 | .116 | .117 | 11 |
| 12 | .118 | .119 | .120 | .121 | .122 | .123 | .124 | .125 | .125 | .126 | 12 |
| 13 | .127 | .128 | .129 | .130 | .131 | .132 | .133 | .134 | .135 | .136 | 13 |
| 14 | .137 | .138 | .139 | .140 | .141 | .142 | .143 | .144 | .145 | .146 | 14 |
| 15 | .147 | .148 | .149 | .150 | .151 | .152 | .153 | .154 | .155 | .156 | 15 |
| 16 | .157 | .158 | .159 | .160 | .161 | .162 | .163 | .164 | .165 | .166 | 16 |
| 17 | .167 | .168 | .169 | .170 | .171 | .172 | .173 | .174 | .175 | .175 | 17 |
| 18 | .176 | .177 | .178 | .179 | .180 | .181 | .182 | .183 | .184 | .185 | 18 |
| 19 | .186 | .187 | .188 | .189 | .190 | .191 | .192 | .193 | .194 | .195 | 19 |
| 20 | .196 | .197 | .198 | .199 | .200 | .201 | .202 | .203 | .204 | .205 | 20 |
| 21 | .206 | .207 | .208 | .209 | .210 | .211 | .212 | .213 | .214 | .215 | 21 |
| 22 | .216 | .217 | .218 | .219 | .220 | .221 | .222 | .223 | .224 | .225 | 22 |
| 23 | .225 | .226 | .227 | .228 | .229 | .230 | .231 | .232 | .233 | .234 | 23 |
| 24 | .235 | .236 | .237 | .238 | .239 | .240 | .241 | .242 | .243 | .244 | 24 |
| 25 | .245 | .246 | .247 | .248 | .249 | .250 | .251 | .252 | .253 | .254 | 25 |
| 26 | .255 | .256 | .257 | .258 | .259 | .260 | .261 | .262 | .263 | .264 | 26 |
| 27 | .265 | .266 | .267 | .268 | .269 | .270 | .271 | .272 | .273 | .274 | 27 |
| 28 | .275 | .275 | .276 | .277 | .278 | .279 | .280 | .281 | .282 | .283 | 28 |
| 29 | .284 | .285 | .286 | .287 | .288 | .289 | .290 | .291 | .292 | .293 | 29 |

FERRIC OXIDE, $Fe_2O_3$. MOLECULAR WEIGHT, 160.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .001 | .002 | .003 | .003 | .004 | .004 | .005 | .006 | 0 |
| 1 | .006 | .007 | .008 | .008 | .009 | .009 | .010 | .011 | .011 | .012 | 1 |
| 2 | .013 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .018 | .018 | 2 |
| 3 | .019 | .019 | .020 | .021 | .021 | .022 | .023 | .023 | .024 | .024 | 3 |
| 4 | .025 | .026 | .026 | .027 | .028 | .028 | .029 | .029 | .030 | .031 | 4 |
| 5 | .031 | .032 | .033 | .033 | .034 | .034 | .035 | .036 | .036 | .037 | 5 |
| 6 | .038 | .038 | .039 | .039 | .040 | .041 | .041 | .042 | .043 | .043 | 6 |
| 7 | .044 | .044 | .045 | .046 | .046 | .047 | .048 | .048 | .049 | .049 | 7 |
| 8 | .050 | .051 | .051 | .052 | .053 | .053 | .054 | .054 | .055 | .056 | 8 |
| 9 | .056 | .057 | .058 | .058 | .059 | .059 | .060 | .061 | .061 | .062 | 9 |
| 10 | .063 | .063 | .064 | .064 | .065 | .066 | .066 | .067 | .068 | .068 | 10 |
| 11 | .069 | .069 | .070 | .071 | .071 | .072 | .073 | .073 | .074 | .074 | 11 |
| 12 | .075 | .076 | .076 | .077 | .078 | .078 | .079 | .079 | .080 | .081 | 12 |
| 13 | .081 | .082 | .083 | .083 | .084 | .084 | .085 | .086 | .086 | .087 | 13 |
| 14 | .088 | .088 | .089 | .089 | .090 | .091 | 091 | .092 | .093 | .093 | 14 |
| 15 | .094 | .094 | .095 | .096 | .096 | .097 | .098 | .098 | .099 | .099 | 15 |
| 16 | .100 | .101 | .101 | .102 | .103 | .103 | .104 | .104 | .105 | .106 | 16 |
| 17 | .106 | .107 | .108 | .108 | .109 | .109 | .110 | .111 | .111 | .112 | 17 |
| 18 | .113 | .113 | .114 | .114 | .115 | .116 | .116 | .117 | .118 | .118 | 18 |
| 19 | .119 | .119 | .120 | .121 | .121 | .122 | .123 | .123 | .124 | .124 | 19 |

### FERROUS OXIDE, $\mathrm{FeO}$. MOLECULAR WEIGHT, 72.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .006 | .007 | .008 | .010 | .011 | .013 | 0 |
| 1 | .014 | .015 | .017 | .018 | .019 | .021 | .022 | .024 | .025 | .026 | 1 |
| 2 | .028 | .029 | .031 | .032 | .033 | .035 | .036 | .038 | .039 | .040 | 2 |
| 3 | .042 | .043 | .044 | .046 | .047 | .049 | .050 | .051 | .053 | .054 | 3 |
| 4 | .056 | .057 | .058 | .060 | .061 | .063 | .064 | .065 | .067 | .068 | 4 |
| 5 | .069 | .071 | .072 | .074 | .075 | .076 | .078 | .079 | .081 | .082 | 5 |
| 6 | .083 | .085 | .086 | .088 | .089 | .090 | .092 | .093 | .094 | .096 | 6 |
| 7 | .097 | .099 | .100 | .101 | .103 | .104 | .106 | .107 | .108 | .110 | 7 |
| 8 | .111 | .113 | .114 | .115 | .117 | .118 | .119 | .121 | .122 | .124 | 8 |
| 9 | .125 | .126 | .128 | .129 | .131 | .132 | .133 | .135 | .136 | .138 | 9 |
| 10 | .139 | .140 | .142 | .143 | .144 | .146 | .147 | .149 | .150 | .151 | 10 |
| 11 | .153 | .154 | .156 | .157 | .158 | .160 | .161 | .163 | .164 | .165 | 11 |
| 12 | .167 | .168 | .169 | .171 | .172 | .174 | .175 | .176 | .178 | .179 | 12 |
| 13 | .181 | .182 | .183 | .185 | .186 | .188 | .189 | .190 | .192 | .193 | 13 |
| 14 | .194 | .196 | .197 | .199 | .200 | .201 | .203 | .204 | .206 | .207 | 14 |
| 15 | .208 | .210 | .211 | .213 | .214 | .215 | .217 | .218 | .219 | .221 | 15 |
| 16 | .222 | .224 | .225 | .226 | .228 | .229 | .231 | .232 | .233 | .235 | 16 |
| 17 | .236 | .238 | .239 | .240 | .242 | .243 | .244 | .246 | .247 | .249 | 17 |
| 18 | .250 | .251 | .253 | .254 | .256 | .257 | .258 | .260 | .261 | .263 | 18 |
| 19 | .264 | .265 | .267 | .268 | .269 | .271 | .272 | .274 | .275 | .276 | 19 |

### MAGNESIA, MgO. MOLECULAR WEIGHT, 40.

Divide percentage weight by 40.

### LIME, CaO. MOLECULAR WEIGHT, 56.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .002 | .004 | .005 | .007 | .009 | .011 | .013 | .014 | .016 | 0 |
| 1 | .018 | .020 | .021 | .023 | .025 | .027 | .029 | .030 | .032 | .034 | 1 |
| 2 | .036 | .038 | .039 | .041 | .043 | .045 | .046 | .048 | .050 | .052 | 2 |
| 3 | .054 | .055 | .057 | .059 | .061 | .063 | .064 | .066 | .068 | .070 | 3 |
| 4 | .071 | .073 | .075 | .077 | .079 | .080 | .082 | .084 | .086 | .088 | 4 |
| 5 | .089 | .091 | .093 | .095 | .096 | .098 | .100 | .102 | .104 | .105 | 5 |
| 6 | .107 | .109 | .111 | .113 | .114 | .116 | .118 | .120 | .121 | .123 | 6 |
| 7 | .125 | .127 | .129 | .130 | .132 | .134 | .136 | .138 | .139 | .141 | 7 |
| 8 | .143 | .145 | .146 | .148 | .150 | .152 | .154 | .155 | .157 | .159 | 8 |
| 9 | .161 | .163 | .164 | .166 | .168 | .170 | .171 | .173 | .175 | .177 | 9 |
| 10 | .179 | .180 | .182 | .184 | .186 | .188 | .189 | .191 | .193 | .195 | 10 |
| 11 | .196 | .198 | .200 | .202 | .204 | .205 | .207 | .209 | .211 | .213 | 11 |
| 12 | .214 | .216 | .218 | .220 | .221 | .223 | .225 | .227 | .229 | .230 | 12 |
| 13 | .232 | .234 | .236 | .238 | .239 | .241 | .243 | .245 | .246 | .248 | 13 |
| 14 | .250 | .252 | .254 | .255 | .257 | .259 | .261 | .263 | .264 | .266 | 14 |
| 15 | .268 | .270 | .271 | .273 | .275 | .277 | .279 | .280 | .282 | .284 | 15 |
| 16 | .286 | .288 | .289 | .291 | .293 | .295 | .296 | .298 | .300 | .302 | 16 |
| 17 | .304 | .305 | .307 | .309 | .311 | .313 | .314 | .316 | .318 | .320 | 17 |
| 18 | .321 | .323 | .325 | .327 | .329 | .330 | .332 | .334 | .336 | .338 | 18 |
| 19 | .339 | .341 | .343 | .345 | .346 | .348 | .350 | .352 | .354 | .355 | 19 |

### SODA, $Na_2O$. MOLECULAR WEIGHT, 62.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .002 | .003 | .005 | .006 | .008 | .010 | .011 | .013 | .015 | 0 |
| 1 | .016 | .018 | .019 | .021 | .023 | .024 | .026 | .027 | .029 | .031 | 1 |
| 2 | .032 | .034 | .035 | .037 | .039 | .040 | .042 | .044 | .045 | .047 | 2 |
| 3 | .048 | .050 | .052 | .053 | .055 | .056 | .058 | .060 | .061 | .063 | 3 |
| 4 | .065 | .066 | .068 | .069 | .071 | .073 | .074 | .076 | .077 | .079 | 4 |
| 5 | .081 | .082 | .084 | .085 | .087 | .089 | .090 | .092 | .094 | .095 | 5 |
| 6 | .097 | .098 | .100 | .102 | .103 | .105 | .106 | .108 | .110 | .111 | 6 |
| 7 | .113 | .115 | .116 | .118 | .119 | .121 | .123 | .124 | .126 | .127 | 7 |
| 8 | .129 | .131 | .132 | .134 | .135 | .137 | .139 | .140 | .142 | .144 | 8 |
| 9 | .145 | .147 | .148 | .150 | .152 | .153 | .155 | .156 | .158 | .160 | 9 |
| 10 | .161 | .163 | .165 | .166 | .168 | .169 | .171 | .173 | .174 | .176 | 10 |
| 11 | .177 | .179 | .181 | .182 | .184 | .185 | .187 | .189 | .190 | .192 | 11 |
| 12 | .194 | .195 | .197 | .198 | .200 | .202 | .203 | .205 | .206 | .208 | 12 |
| 13 | .210 | .211 | .213 | .215 | .216 | .218 | .219 | .221 | .223 | .224 | 13 |
| 14 | .226 | .227 | .229 | .231 | .232 | .234 | .235 | .237 | .239 | .240 | 14 |
| 15 | .242 | .244 | .245 | .247 | .248 | .250 | .252 | .253 | .255 | .256 | 15 |
| 16 | .258 | .260 | .261 | .263 | .265 | .266 | .268 | .269 | .271 | .273 | 16 |
| 17 | .274 | .276 | .277 | .279 | .281 | .282 | .284 | .285 | .287 | .289 | 17 |
| 18 | .290 | .292 | .294 | .295 | .297 | .298 | .300 | .302 | .303 | .305 | 18 |
| 19 | .306 | .308 | .310 | .311 | .313 | .315 | .316 | .318 | .319 | .321 | 19 |

### POTASH, $K_2O$. MOLECULAR WEIGHT, 94.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .009 | .010 | 0 |
| 1 | .011 | .012 | .013 | .014 | .015 | .016 | .017 | .018 | .019 | .020 | 1 |
| 2 | .021 | .022 | .023 | .024 | .026 | .027 | .028 | .029 | .030 | .031 | 2 |
| 3 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | 3 |
| 4 | .043 | .044 | .045 | .046 | .047 | .048 | .049 | .050 | .051 | .052 | 4 |
| 5 | .053 | .054 | .055 | .056 | .057 | .059 | .060 | .061 | .062 | .063 | 5 |
| 6 | .064 | .065 | .066 | .067 | .068 | .069 | .070 | .071 | .072 | .073 | 6 |
| 7 | .074 | .076 | .077 | .078 | .079 | .080 | .081 | .082 | .083 | .084 | 7 |
| 8 | .085 | .086 | .087 | .088 | .089 | .090 | .091 | .093 | .094 | .095 | 8 |
| 9 | .096 | .097 | .098 | .099 | .100 | .101 | .102 | .103 | .104 | .105 | 9 |
| 10 | .106 | .107 | .109 | .110 | .111 | .112 | .113 | .114 | .115 | .116 | 10 |
| 11 | .117 | .118 | .119 | .120 | .121 | .122 | .123 | .124 | .126 | .127 | 11 |
| 12 | .128 | .129 | .130 | .131 | .132 | .133 | .134 | .135 | .136 | .137 | 12 |
| 13 | .138 | .139 | .140 | .141 | .143 | .144 | .145 | .146 | .147 | .148 | 13 |
| 14 | .149 | .150 | .151 | .152 | .153 | .154 | .155 | .156 | .157 | .159 | 14 |
| 15 | .160 | .161 | .162 | .163 | .164 | .165 | .166 | .167 | .168 | .169 | 15 |
| 16 | .170 | .171 | .172 | .173 | .174 | .176 | .177 | .178 | .179 | .180 | 16 |
| 17 | .181 | .182 | .183 | .184 | .185 | .186 | .187 | .188 | .189 | .190 | 17 |
| 18 | .191 | .193 | .194 | .195 | .196 | .197 | .198 | .199 | .200 | .201 | 18 |
| 19 | .202 | .203 | .204 | .205 | .206 | .207 | .209 | .210 | .211 | .212 | 19 |

### WATER, $H_2O$. MOLECULAR WEIGHT, 18.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .006 | .011 | .017 | .022 | .028 | .033 | .039 | .044 | .050 | 0 |
| 1 | .056 | .061 | .067 | .072 | .078 | .083 | .089 | .094 | .100 | .106 | 1 |
| 2 | .111 | .117 | .122 | .128 | .133 | .139 | .144 | .150 | .156 | .161 | 2 |
| 3 | .167 | .172 | .178 | .183 | .189 | .194 | .200 | .206 | .211 | .217 | 3 |
| 4 | .222 | .228 | .233 | .239 | .244 | .250 | .256 | .261 | .267 | .272 | 4 |
| 5 | .278 | .283 | .289 | .294 | .300 | .306 | .311 | .317 | .322 | .328 | 5 |
| 6 | .333 | .339 | .344 | .350 | .356 | .361 | .367 | .372 | .378 | .383 | 6 |
| 7 | .389 | .394 | .400 | .406 | .411 | .417 | .422 | .428 | .433 | .439 | 7 |
| 8 | .444 | .450 | .456 | .461 | .467 | .472 | .478 | .483 | .489 | .494 | 8 |
| 9 | .500 | .506 | .511 | .517 | .522 | .528 | .533 | .539 | .544 | .550 | 9 |

### CARBONIC ACID, $CO_2$. MOLECULAR WEIGHT, 44.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .002 | .005 | .007 | .009 | .011 | .014 | .016 | .018 | .020 | 0 |
| 1 | .023 | .025 | .027 | .030 | .032 | .034 | .036 | .039 | .041 | .043 | 1 |
| 2 | .045 | .048 | .050 | .052 | .055 | .057 | .059 | .061 | .064 | .066 | 2 |
| 3 | .068 | .070 | .073 | .075 | .077 | .080 | .082 | .084 | .086 | .089 | 3 |
| 4 | .091 | .093 | .095 | .098 | .100 | .102 | .105 | .107 | .109 | .111 | 4 |
| 5 | .114 | .116 | .118 | .120 | .123 | .125 | .127 | .130 | .132 | .134 | 5 |
| 6 | .136 | .139 | .141 | .143 | .145 | .148 | .150 | .152 | .155 | .157 | 6 |
| 7 | .159 | .161 | .164 | .166 | .168 | .170 | .173 | .175 | .177 | .180 | 7 |
| 8 | .182 | .184 | .186 | .189 | .191 | .193 | .195 | .198 | .200 | .202 | 8 |
| 9 | .205 | .207 | .209 | .211 | .214 | .216 | .218 | .220 | .223 | .225 | 9 |

### TITANIC ACID, $TiO_2$. MOLECULAR WEIGHT, 80.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .005 | .006 | .008 | .009 | .010 | .011 | 0 |
| 1 | .013 | .014 | .015 | .016 | .018 | .019 | .020 | .021 | .023 | .024 | 1 |
| 2 | .025 | .026 | .028 | .029 | .030 | .031 | .033 | .034 | .035 | .036 | 2 |
| 3 | .038 | .039 | .040 | .041 | .043 | .044 | .045 | .046 | .048 | .049 | 3 |
| 4 | .050 | .051 | .053 | .054 | .055 | .056 | .058 | .059 | .060 | .061 | 4 |
| 5 | .063 | .064 | .065 | .066 | .068 | .069 | .070 | .071 | .073 | .074 | 5 |
| 6 | .075 | .076 | .078 | .079 | .080 | .081 | .083 | .084 | .085 | .086 | 6 |
| 7 | .088 | .089 | .090 | .091 | .093 | .094 | .095 | .096 | .098 | .099 | 7 |
| 8 | .100 | .101 | .103 | .104 | .105 | .106 | .108 | .109 | .110 | .111 | 8 |
| 9 | .113 | .114 | .115 | .116 | .118 | .119 | .120 | .121 | .123 | .124 | 9 |

### ZIRCONIA, $ZrO_2$. MOLECULAR WEIGHT, 123.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .002 | .002 | .003 | .004 | .005 | .006 | .007 | .007 | 0 |
| 1 | .008 | .009 | .010 | .011 | .011 | .012 | .013 | .014 | .015 | .015 | 1 |
| 2 | .016 | .017 | .018 | .019 | .020 | .020 | .021 | .022 | .023 | .024 | 2 |
| 3 | .024 | .025 | .026 | .027 | .028 | .028 | .029 | .030 | .031 | .032 | 3 |
| 4 | .033 | .033 | .034 | .035 | .036 | .037 | .037 | .038 | .039 | .040 | 4 |
| 5 | .041 | .042 | .042 | .043 | .044 | .045 | .046 | .046 | .047 | .048 | 5 |

### PHOSPHORIC PENTOXIDE, $P_2O_5$. MOLECULAR WEIGHT, 142.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .001 | .002 | .003 | .004 | .004 | .005 | .006 | .006 | 0 |
| 1 | .007 | .008 | .008 | .009 | .010 | .011 | 011 | .012 | .013 | .013 | 1 |
| 2 | .014 | .015 | .015 | .016 | .017 | .018 | .018 | .019 | .020 | .020 | 2 |
| 3 | .021 | .022 | .023 | .023 | .024 | .025 | .025 | .026 | .027 | .027 | 3 |
| 4 | .028 | .029 | .030 | .030 | .031 | .032 | .032 | .033 | .034 | .035 | 4 |
| 5 | .035 | .036 | .037 | .037 | .038 | .039 | .039 | .040 | .041 | .042 | 5 |

### SULPHURIC ANHYDRIDE, $SO_3$. MOLECULAR WEIGHT, 80.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .005 | .006 | .008 | .009 | .010 | .011 | 0 |
| 1 | .013 | .014 | .015 | .016 | .018 | .019 | .020 | .021 | .023 | .024 | 1 |
| 2 | .025 | .026 | .028 | .029 | .030 | .031 | .033 | .034 | .035 | .036 | 2 |
| 3 | .038 | .039 | .040 | .041 | .043 | .044 | .045 | .046 | .048 | .049 | 3 |
| 4 | .050 | .051 | .053 | .054 | .055 | .056 | .058 | .059 | .060 | .061 | 4 |

### CHLORINE, Cl. MOLECULAR WEIGHT, 35.5.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .003 | .006 | .009 | .011 | .014 | .017 | .020 | .023 | .025 | 0 |
| 1 | .028 | .031 | .034 | .037 | .039 | .042 | .045 | .048 | .051 | .054 | 1 |
| 2 | .056 | .059 | .062 | .065 | .068 | .070 | .073 | .076 | .079 | .082 | 2 |
| 3 | .085 | .087 | .090 | .093 | .096 | .099 | .101 | .104 | .107 | .110 | 3 |

### FLUORINE, F. MOLECULAR WEIGHT, 19.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .005 | .011 | .016 | .021 | .026 | .032 | .037 | .042 | .047 | 0 |
| 1 | .053 | .058 | .063 | .068 | .074 | .079 | .084 | .089 | .095 | .100 | 1 |

### SULPHUR, S. MOLECULAR WEIGHT, 32.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .003 | .006 | .009 | .013 | .016 | .019 | .022 | .025 | .028 | 0 |
| 1 | .031 | .034 | .038 | .041 | .044 | .047 | .050 | .053 | .056 | .059 | 1 |
| 2 | .063 | .066 | .069 | .072 | .075 | .078 | .081 | .084 | .088 | .091 | 2 |
| 3 | .094 | .097 | .100 | .103 | .106 | .109 | .113 | .116 | .119 | .122 | 3 |
| 4 | .125 | .128 | .131 | .134 | .138 | .141 | .144 | .147 | .150 | .153 | 4 |
| 5 | .156 | .159 | .163 | .166 | .169 | .172 | .175 | .178 | .181 | .184 | 5 |

### CHROMIC OXIDE, $Cr_2O_3$. MOLECULAR WEIGHT, 152.

| % | .0 | .1 | 2. | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .001 | .002 | .003 | .003 | .004 | .005 | .005 | .006 | 0 |
| 1 | .007 | .007 | .008 | .009 | .009 | .010 | .011 | .011 | .012 | .013 | 1 |
| 2 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .018 | .018 | .019 | 2 |
| 3 | .020 | .020 | .021 | .022 | .022 | .023 | .024 | .024 | .025 | .026 | 3 |
| 4 | .026 | .027 | .028 | .028 | .029 | .030 | .030 | .031 | .032 | .032 | 4 |
| 5 | .033 | .034 | .034 | .035 | .036 | .036 | .037 | .038 | .038 | .039 | 5 |

### NICKEL OXIDE, NiO. MOLECULAR WEIGHT, 75.
### COBALT OXIDE, CoO. MOLECULAR WEIGHT, 75.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .005 | .007 | .008 | .009 | .011 | .012 | 0 |
| 1 | .013 | .015 | .016 | .017 | .019 | .020 | .021 | .023 | .024 | .025 | 1 |
| 2 | .027 | .028 | .029 | .031 | .032 | .033 | .035 | .036 | .037 | .039 | 2 |
| 3 | .040 | .041 | .043 | .044 | .045 | .047 | .048 | .049 | .051 | .052 | 3 |

### CUPRIC OXIDE, CuO. MOLECULAR WEIGHT, 79.5.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .005 | .006 | .008 | .009 | .010 | .011 | 0 |

### MANGANOUS OXIDE, MnO. MOLECULAR WEIGHT, 71.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .003 | .004 | .006 | .007 | .008 | .010 | .011 | .013 | 0 |
| 1 | .014 | .015 | .017 | .018 | .020 | .021 | .023 | .024 | .025 | .027 | 1 |
| 2 | .028 | .030 | .031 | .032 | .034 | .035 | .037 | .038 | .039 | .041 | 2 |
| 3 | .042 | .044 | .045 | .046 | .048 | .049 | .051 | .052 | .054 | .055 | 3 |

### BARYTA, BaO. MOLECULAR WEIGHT, 153.5.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .001 | .002 | .003 | .003 | .004 | .005 | .005 | .006 | 0 |
| 1 | .007 | .007 | .008 | .009 | .009 | .010 | .010 | .011 | .012 | .012 | 1 |
| 2 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .018 | .018 | .019 | 2 |
| 3 | .020 | .020 | .021 | .022 | .022 | .023 | .024 | .024 | .025 | .026 | 3 |

STRONTIA, SrO. MOLECULAR WEIGHT, 103.5.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | 0 |
| 1 | .010 | .011 | .012 | .013 | .014 | .014 | .015 | .016 | .017 | .018 | 1 |

LITHIA, $Li_2O$. MOLECULAR WEIGHT, 30.

| % | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .003 | .007 | .010 | .013 | .017 | .020 | .023 | .027 | .030 | 0 |
| 1 | .033 | .037 | .040 | .043 | .047 | .050 | .053 | .057 | .060 | .063 | 1 |

# PERCENTAGE WEIGHTS FOR VARIOUS PROPORTIONS OF MOLECULES OF THE STANDARD ROCK-MAKING MINERALS.

## QUARTZ, $SiO_2$, MOLECULAR WEIGHT, 60.

Multiply the molecular proportion of $SiO_2$ by 60.

## ORTHOCLASE, $K_2O.\ Al_2O_3.\ 6SiO_2$. MOLECULAR WEIGHT, 556.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .56 | 1.11 | 1.67 | 2.22 | 2.78 | 3.34 | 3.89 | 4.45 | 5.00 | .00 |
| .01 | 5.56 | 6.12 | 6.67 | 7.23 | 7.78 | 8.34 | 8.90 | 9.45 | 10.01 | 10.56 | .01 |
| .02 | 11.12 | 11.68 | 12.23 | 12.79 | 13.34 | 13.90 | 14.46 | 15.01 | 15.57 | 16.12 | .02 |
| .03 | 16.68 | 17.24 | 17.79 | 18.35 | 18.90 | 19.46 | 20.02 | 20.57 | 21.13 | 21.68 | .03 |
| .04 | 22.24 | 22.80 | 23.35 | 23.91 | 24.46 | 25.02 | 25.58 | 26.13 | 26.69 | 27.24 | .04 |
| .05 | 27.80 | 28.36 | 28.91 | 29.47 | 30.02 | 30.58 | 31.14 | 31.69 | 32.25 | 32.80 | .05 |
| .06 | 33.36 | 33.92 | 34.47 | 35.03 | 35.58 | 36.14 | 36.70 | 37.25 | 37.81 | 38.36 | .06 |
| .07 | 38.92 | 39.48 | 40.03 | 40.59 | 41.14 | 41.70 | 42.26 | 42.81 | 43.37 | 43.92 | .07 |
| .08 | 44.48 | 45.04 | 45.59 | 46.15 | 46.70 | 47.26 | 47.82 | 48.37 | 48.93 | 49.48 | .08 |
| .09 | 50.04 | 50.60 | 51.15 | 51.71 | 52.26 | 52.82 | 53.38 | 53.93 | 54.49 | 55.04 | .09 |
| .10 | 55.60 | 56.16 | 56.71 | 57.27 | 57.82 | 58.38 | 58.94 | 59.49 | 60.05 | 60.60 | .10 |
| .11 | 61.16 | 61.72 | 62.27 | 62.83 | 63.38 | 63.94 | 64.50 | 65.05 | 65.61 | 66.16 | .11 |
| .12 | 66.72 | 67.28 | 67.83 | 68.39 | 68.94 | 69.50 | 70.06 | 70.61 | 71.17 | 71.72 | .12 |
| .13 | 72.28 | 72.84 | 73.39 | 73.95 | 74.50 | 75.06 | 75.62 | 76.17 | 76.73 | 77.28 | .13 |
| .14 | 77.84 | 78.40 | 78.95 | 79.51 | 80.06 | 80.62 | 81.18 | 81.73 | 82.29 | 82.84 | .14 |
| .15 | 83.40 | 83.96 | 84.51 | 85.07 | 85.62 | 86.18 | 86.74 | 87.39 | 87.85 | 88.40 | .15 |
| .16 | 88.96 | 89.52 | 90.07 | 90.63 | 91.18 | 91.74 | 92.30 | 92.85 | 93.41 | 93.96 | .16 |
| .17 | 94.52 | 95.08 | 95.63 | 96.19 | 96.74 | 97.30 | 97.85 | 98.41 | 98.97 | 99.52 | .17 |
| .18 | 100.08 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .18 |

ALBITE, $Na_2O . Al_2O_3 . 6SiO_2$. MOLECULAR WEIGHT, 524.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .52 | 1.05 | 1.57 | 2.10 | 2.62 | 3.14 | 3.67 | 4.19 | 4.72 | .00 |
| .01 | 5.24 | 5.76 | 6.29 | 6.81 | 7.34 | 7.86 | 8.38 | 8.91 | 9.43 | 9.96 | .01 |
| .02 | 10.48 | 11.00 | 11.53 | 12.05 | 12.58 | 13.10 | 13.62 | 14.15 | 14.67 | 15.20 | .02 |
| .03 | 15.72 | 16.24 | 16.77 | 17.29 | 17.82 | 18.34 | 18.86 | 19.39 | 19.91 | 20.44 | .03 |
| .04 | 20.96 | 21.48 | 22.01 | 22.53 | 23.06 | 23.58 | 24.10 | 24.63 | 25.15 | 25.68 | .04 |
| .05 | 26.20 | 26.72 | 27.25 | 27.77 | 28.30 | 28.82 | 29.34 | 29.87 | 30.39 | 30.92 | .05 |
| .06 | 31.44 | 31.96 | 32.49 | 33.01 | 33.54 | 34.06 | 34.58 | 35.11 | 35.63 | 36.15 | .06 |
| .07 | 36.68 | 37.20 | 37.73 | 38.25 | 38.77 | 39.30 | 39.82 | 40.35 | 40.87 | 41.39 | .07 |
| .08 | 41.92 | 42.44 | 42.97 | 43.49 | 44.01 | 44.54 | 45.06 | 45.59 | 46.11 | 46.63 | .08 |
| .09 | 47.16 | 47.68 | 48.21 | 48.73 | 49.25 | 49.78 | 50.30 | 50.83 | 51.35 | 51.87 | .09 |
| .10 | 52.40 | 52.92 | 53.45 | 53.97 | 54.49 | 55.02 | 55.54 | 56.07 | 56.59 | 57.11 | .10 |
| .11 | 57.64 | 58.16 | 58.69 | 59.21 | 59 73 | 60.26 | 60.78 | 61.31 | 61.83 | 62.35 | .11 |
| .12 | 62.88 | 63.40 | 63.93 | 64.45 | 64.97 | 65.50 | 66.02 | 66.55 | 67.07 | 67.59 | .12 |
| .13 | 68.12 | 68.64 | 69.17 | 69.69 | 70.21 | 70.74 | 71.26 | 71.79 | 72.31 | 72.83 | .13 |
| .14 | 73.36 | 73.88 | 74.41 | 75.93 | 75.45 | 76.98 | 76.50 | 77.03 | 77.55 | 78.07 | .14 |
| .15 | 78.60 | 79.12 | 79.65 | 80.17 | 80.70 | 81.22 | 81.72 | 82.28 | 82.79 | 83.32 | .15 |
| .16 | 83.84 | 84.36 | 84.89 | 85.41 | 85.94 | 86.46 | 86.98 | 87.51 | 88.03 | 88.56 | .16 |
| .17 | 89.08 | 89.60 | 90.13 | 90.65 | 91.18 | 91.70 | 92.22 | 92.75 | 93.27 | 93.80 | .17 |
| .18 | 94.32 | 94.84 | 95.37 | 95.89 | 96.42 | 96.94 | 97.46 | 97.99 | 98.51 | 99.04 | .18 |
| .19 | 99.56 | 100.08 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .19 |

### ANORTHITE, $CaO. Al_2O_3. 2 SiO_2$. MOLECULAR WEIGHT, 278.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .28 | .56 | .83 | 1.11 | 1.39 | 1.67 | 1.95 | 2.22 | 2.50 | .00 |
| .01 | 2.78 | 3.06 | 3.34 | 3.61 | 3.89 | 4.17 | 4.45 | 4.73 | 5.00 | 5.28 | .01 |
| .02 | 5.56 | 5.84 | 6.12 | 6.39 | 6.67 | 6.95 | 7.23 | 7.51 | 7.78 | 8.06 | .02 |
| .03 | 8.34 | 8.62 | 8.90 | 9.17 | 9.45 | 9.73 | 10.01 | 10.29 | 10.56 | 10.84 | .03 |
| .04 | 11.12 | 11.40 | 11.68 | 11.95 | 12.23 | 12.51 | 12.79 | 13.07 | 13.34 | 13.62 | .04 |
| .05 | 13.90 | 14.18 | 14.46 | 14.73 | 15.01 | 15.29 | 15.57 | 15.85 | 16.12 | 16.40 | .05 |
| .06 | 16.68 | 16.96 | 17.24 | 17.51 | 17.79 | 18.07 | 18.35 | 18.63 | 18.90 | 19.18 | .06 |
| .07 | 19.46 | 19.74 | 20.02 | 20.29 | 20.57 | 20.85 | 21.13 | 21.41 | 21.68 | 21.96 | .07 |
| .08 | 22.24 | 22.52 | 22.80 | 23.07 | 23.35 | 23.63 | 23.91 | 24.19 | 24.46 | 24.74 | .08 |
| .09 | 25.02 | 25.30 | 25.58 | 25.85 | 26.13 | 26.41 | 26.69 | 26.97 | 27.24 | 27.52 | .09 |
| .10 | 27.80 | 28.08 | 28.36 | 28.63 | 28.91 | 29.19 | 29.47 | 29.75 | 30.02 | 30.30 | .10 |
| .11 | 30.58 | 30.86 | 31.14 | 31.41 | 31.69 | 31.97 | 32.25 | 32.53 | 32.80 | 33.08 | .11 |
| .12 | 33.36 | 33.64 | 33.92 | 34.19 | 34.47 | 34.75 | 35.03 | 35.31 | 35.58 | 35.86 | .12 |
| .13 | 36.14 | 36.42 | 36.70 | 36.97 | 37.25 | 37.53 | 37.81 | 38.09 | 38.36 | 38.64 | .13 |
| .14 | 38.92 | 39.20 | 39.48 | 39.75 | 40.03 | 40.31 | 40.59 | 40.87 | 41.14 | 41.42 | .14 |
| .15 | 41.70 | 41.98 | 42.26 | 42.53 | 42.81 | 43.09 | 43.37 | 43.65 | 43.92 | 44.20 | .15 |
| .16 | 44.48 | 44.76 | 45.04 | 45.31 | 45.59 | 45.87 | 46.15 | 46.43 | 46.70 | 46.98 | .16 |
| .17 | 47.26 | 47.54 | 47.82 | 48.09 | 48.37 | 48.65 | 48.93 | 49.21 | 49.48 | 49.76 | .17 |
| .18 | 50.04 | 50.32 | 50.60 | 50.87 | 51.15 | 51.43 | 51.71 | 51.99 | 52.26 | 52.54 | .18 |
| .19 | 52.82 | 53.10 | 53.38 | 53.65 | 53.93 | 54.21 | 54.49 | 54.77 | 55.04 | 55.32 | .19 |

### LEUCITE, $K_2O . Al_2O_3 . 4SiO_2$. MOLECULAR WEIGHT, 436.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .44 | .87 | 1.31 | 1.74 | 2.18 | 2.62 | 3.05 | 3.49 | 3.92 | .00 |
| .01 | 4.36 | 4.80 | 5.23 | 5.67 | 6.10 | 6.54 | 6.98 | 7.41 | 7.85 | 8.28 | .01 |
| .02 | 8.72 | 9.16 | 9.59 | 10.03 | 10.46 | 10.90 | 11.34 | 11.77 | 12.21 | 12.64 | .02 |
| .03 | 13.08 | 13.52 | 13.95 | 14.39 | 14.82 | 15.26 | 15.70 | 16.13 | 16.57 | 17.00 | .03 |
| .04 | 17.44 | 17.88 | 18.31 | 18.75 | 19.18 | 19.62 | 20.06 | 20.49 | 20.93 | 21.36 | .04 |
| .05 | 21.80 | 22.24 | 22.67 | 23.11 | 23.54 | 23.98 | 24.42 | 24.85 | 25.29 | 25.72 | .05 |
| .06 | 26.16 | 26.60 | 27.03 | 27.47 | 27.90 | 28.34 | 28.78 | 29.21 | 29.65 | 30.08 | .06 |
| .07 | 30.52 | 30.96 | 31.39 | 31.83 | 32.26 | 32.70 | 33.14 | 33.57 | 34.01 | 34.44 | .07 |
| .08 | 34.88 | 35.32 | 35.75 | 36.19 | 36.62 | 37.06 | 37.50 | 37.93 | 38.37 | 38.80 | .08 |
| .09 | 39.24 | 39.68 | 40.11 | 40.55 | 40.98 | 41.42 | 41.86 | 42.29 | 42.73 | 43.16 | .09 |
| .10 | 43.60 | 44.04 | 44.47 | 44.91 | 45.34 | 45.78 | 46.22 | 46.65 | 47.09 | 47.52 | .10 |
| .11 | 47.96 | 48.40 | 48.83 | 49.27 | 49.70 | 50.14 | 50.58 | 51.01 | 51.45 | 51.88 | .11 |
| .12 | 52.32 | 52.76 | 53.19 | 53.63 | 54.06 | 54.50 | 54.94 | 55.37 | 55.81 | 56.24 | .12 |
| .13 | 56.68 | 57.12 | 57.55 | 57.99 | 58.42 | 58.86 | 59.30 | 59.73 | 60.17 | 60.60 | .13 |
| .14 | 61.04 | 61.48 | 61.91 | 62.35 | 62.78 | 63.22 | 63.66 | 64.09 | 64.53 | 64.96 | .14 |

### NEPHELITE, $Na_2O . Al_2O_3 . 2SiO_2$. MOLECULAR WEIGHT, 284.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .28 | .57 | .85 | 1.14 | 1.42 | 1.70 | 1.99 | 2.27 | 2.56 | .00 |
| .01 | 2.84 | 3.12 | 3.41 | 3.69 | 3.98 | 4.26 | 4.54 | 4.83 | 5.11 | 5.40 | .01 |
| .02 | 5.68 | 5.94 | 6.25 | 6.53 | 6.82 | 7.10 | 7.38 | 7.67 | 7.95 | 8.24 | .02 |
| .03 | 8.52 | 8.80 | 9.09 | 9.37 | 9.66 | 9.94 | 10.22 | 10.51 | 10.79 | 11.08 | .03 |
| .04 | 11.36 | 11.64 | 11.93 | 12.21 | 12.50 | 12.78 | 13.06 | 13.35 | 13.63 | 13.92 | .04 |
| .05 | 14.20 | 14.48 | 14.77 | 15.05 | 15.34 | 15.62 | 15.90 | 16.19 | 16.47 | 16.76 | .05 |
| .06 | 17.04 | 17.32 | 17.61 | 17.89 | 18.18 | 18.46 | 18.74 | 19.03 | 19.31 | 19.60 | .06 |
| .07 | 19.88 | 20.16 | 20.45 | 20.73 | 21.02 | 21.30 | 21.58 | 21.87 | 22.15 | 22.44 | .07 |
| .08 | 22.72 | 23.00 | 23.28 | 23.57 | 23.86 | 24.14 | 24.42 | 24.71 | 24.99 | 25.28 | .08 |
| .09 | 25.56 | 25.84 | 26.13 | 26.41 | 26.70 | 26.98 | 27.26 | 27.55 | 27.83 | 28.12 | .09 |
| .10 | 28.40 | 28.68 | 28.97 | 29.25 | 29.54 | 29.82 | 30.10 | 30.39 | 30.67 | 30.96 | .10 |
| .11 | 31.24 | 31.52 | 31.81 | 32.09 | 32.38 | 32.66 | 32.94 | 33.23 | 33.51 | 33.80 | .11 |
| .12 | 34.08 | 34.36 | 34.65 | 34.93 | 35.22 | 35.50 | 35.78 | 36.07 | 36.35 | 36.64 | .12 |
| .13 | 36.92 | 37.20 | 37.49 | 37.77 | 38.06 | 38.34 | 38.62 | 38.91 | 39.19 | 39.48 | .13 |
| .14 | 39.76 | 40.04 | 40.33 | 40.61 | 40.90 | 41.18 | 41.46 | 41.75 | 41.93 | 42.32 | .14 |
| .15 | 42.60 | 42.88 | 43.17 | 43.45 | 43.74 | 44.02 | 44.30 | 44.59 | 44.87 | 45.16 | .15 |
| .16 | 45.44 | 45.72 | 46.01 | 46.29 | 46.58 | 46.86 | 47.14 | 47.43 | 47.71 | 48.00 | .16 |
| .17 | 48.28 | 48.56 | 48.85 | 49.13 | 49.42 | 49.70 | 49.98 | 50.27 | 50.55 | 50.84 | .17 |
| .18 | 51.12 | 51.40 | 51.69 | 51.97 | 52.26 | 52.54 | 52.82 | 53.11 | 53.39 | 53.68 | .18 |
| .19 | 53.96 | 54.24 | 54.53 | 54.81 | 55.10 | 55.38 | 56.66 | 55.95 | 56.23 | 56.52 | .19 |

### SODIUM CHLORIDE, $Na_2Cl_2$. MOLECULAR WEIGHT, 117.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .12 | .23 | .35 | .47 | .59 | .70 | .82 | .94 | 1.05 | .00 |
| .01 | 1.17 | 1.29 | 1.40 | 1.52 | 1.64 | 1.76 | 1.87 | 1.99 | 2.11 | 2.22 | .01 |
| .02 | 2.34 | 2.46 | 2.57 | 2.69 | 2.81 | 2.93 | 3.04 | 3.16 | 3.28 | 3.39 | .02 |
| .03 | 3.51 | 3.63 | 3.74 | 3.86 | 3.98 | 4.10 | 4.21 | 4.33 | 4.45 | 4.56 | .03 |
| .04 | 4.68 | 4.80 | 4.91 | 5.03 | 5.15 | 5.27 | 5.38 | 5.50 | 5.62 | 5.73 | .04 |

### SODIUM SULPHATE, $Na_2SO_4$. MOLECULAR WEIGHT, 142.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .14 | .28 | .43 | .57 | .71 | .85 | .99 | 1.14 | 1.28 | .00 |
| .01 | 1.42 | 1.56 | 1.70 | 1.85 | 1.99 | 2.13 | 2.27 | 2.41 | 2.56 | 2.70 | .01 |
| .02 | 2.84 | 2.98 | 3.12 | 3.27 | 3.41 | 3.55 | 3.69 | 3.83 | 3.98 | 4.12 | .02 |
| .03 | 4.26 | 4.40 | 4.54 | 4.69 | 4.83 | 4.97 | 5.11 | 5.25 | 5.40 | 5.54 | .03 |
| .04 | 5.68 | 5.82 | 5.96 | 6.11 | 6.25 | 6.39 | 6.53 | 6.67 | 6.82 | 6.96 | .04 |

### CORUNDUM, $Al_2O_3$. MOLECULAR WEIGHT, 102.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .10 | .20 | .31 | .41 | .51 | .61 | .71 | .82 | .92 | .00 |
| .01 | 1.02 | 1.12 | 1.22 | 1.33 | 1.43 | 1.53 | 1.63 | 1.73 | 1.84 | 1.94 | .01 |
| .02 | 2.04 | 2.14 | 2.24 | 2.35 | 2.45 | 2.55 | 2.65 | 2.75 | 2.86 | 2.96 | .02 |
| .03 | 3.06 | 3.16 | 3.26 | 3.37 | 3.47 | 3.57 | 3.67 | 3.77 | 3.88 | 3.98 | .03 |
| .04 | 4.08 | 4.18 | 4.28 | 4.39 | 4.49 | 4.59 | 4.69 | 4.79 | 4.90 | 5.00 | .04 |
| .05 | 5.10 | 5.20 | 5.30 | 5.41 | 5.51 | 5.61 | 5.71 | 5.81 | 5.92 | 6.02 | .05 |
| .06 | 6.12 | 6.22 | 6.32 | 6.43 | 6.53 | 6.63 | 6.73 | 6.83 | 6.94 | 7.04 | .06 |
| .07 | 7.14 | 7.24 | 7.34 | 7.45 | 7.55 | 7.65 | 7.75 | 7.85 | 7.96 | 8.06 | .07 |
| .08 | 8.16 | 8.26 | 8.36 | 8.47 | 8.57 | 8.67 | 8.77 | 8.87 | 8.98 | 9.08 | .08 |
| .09 | 9.18 | 9.28 | 9.38 | 9.49 | 9.59 | 9.69 | 9.76 | 9.89 | 10.00 | 10.10 | .09 |

### ZIRCON, $ZrO_2.SiO_2$. MOLECULAR WEIGHT, 183.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .18 | .37 | .55 | .73 | .91 | 1.10 | 1.28 | 1.46 | 1.65 | .00 |
| .01 | 1.83 | 2.01 | 2.20 | 2.38 | 2.56 | 2.75 | 2.93 | 3.11 | 3.29 | 3.48 | .01 |
| .02 | 3.66 | 3.84 | 4.03 | 4.21 | 4.39 | 4.58 | 4.76 | 4.94 | 5.12 | 5.31 | .02 |
| .03 | 5.49 | 5.67 | 5.86 | 6.04 | 6.22 | 6.41 | 6.59 | 6.77 | 6.95 | 7.14 | .03 |
| .04 | 7.32 | 7.50 | 7.78 | 7.87 | 8.05 | 8.24 | 8.42 | 8.60 | 8.78 | 8.97 | .04 |

ACMITE, $Na_2O . Fe_2O_3 . 4SiO_2$. MOLECULAR WEIGHT, 462.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .46 | .92 | 1.39 | 1.85 | 2.31 | 2.77 | 3.23 | 3.70 | 4.16 | .00 |
| .01 | 4.62 | 5.08 | 5.54 | 6.01 | 6.47 | 6.93 | 7.39 | 7.85 | 8.32 | 8.78 | .01 |
| .02 | 9.24 | 9.70 | 10.16 | 10.63 | 11.09 | 11.55 | 12.01 | 12.47 | 12.94 | 13.40 | .02 |
| .03 | 13.86 | 14.32 | 14.78 | 15.25 | 15.71 | 16.17 | 16.63 | 17.09 | 17.56 | 18.02 | .03 |
| .04 | 18.48 | 18.94 | 19.40 | 19.87 | 20.33 | 20.79 | 21.25 | 21.71 | 22.18 | 22.64 | .04 |
| .05 | 23.10 | 23.56 | 24.02 | 24.49 | 24.95 | 25.41 | 25.87 | 26.33 | 26.80 | 27.26 | .05 |
| .06 | 27.72 | 28.18 | 28.64 | 29.11 | 29.57 | 30.03 | 30.49 | 30.95 | 31.42 | 31.88 | .06 |
| .07 | 32.34 | 32.80 | 33.26 | 33.73 | 34.19 | 34.65 | 35.11 | 35.57 | 36.04 | 36.50 | .07 |
| .08 | 36.96 | 37.42 | 37.88 | 38.35 | 38.81 | 39.27 | 39.73 | 40.19 | 40.66 | 41.12 | .08 |
| .09 | 41.58 | 42.04 | 42.50 | 42.97 | 43.43 | 43.89 | 44.35 | 44.81 | 45.28 | 45.74 | .09 |

SODIUM METASILICATE, $Na_2O.SiO_2$. MOLECULAR WEIGHT, 122.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .12 | .24 | .37 | .49 | .61 | .73 | .85 | .98 | 1.10 | .00 |
| .01 | 1.22 | 1.34 | 1.46 | 1.59 | 1.71 | 1.83 | 1.95 | 2.07 | 2.20 | 2.32 | .01 |
| .02 | 2.44 | 2.56 | 2.68 | 2.81 | 2.93 | 3.05 | 3.17 | 3.29 | 3.42 | 3.54 | .02 |
| .03 | 3.66 | 3.78 | 3.90 | 4.03 | 4.15 | 4.27 | 4.39 | 4.51 | 4.64 | 4.76 | .03 |
| .04 | 4.88 | 5.00 | 5.12 | 5.25 | 5.37 | 5.49 | 5.61 | 5.73 | 5.86 | 5.98 | .04 |
| .05 | 6.10 | 6.22 | 6.34 | 6.47 | 6.59 | 6.71 | 6.83 | 6.95 | 7.08 | 7.20 | .05 |
| .06 | 7.32 | 7.44 | 7.56 | 7.69 | 7.81 | 7.93 | 8.05 | 8.17 | 8.30 | 8.42 | .06 |
| .07 | 8.54 | 8.66 | 8.78 | 8.91 | 9.03 | 9.15 | 9.27 | 9.39 | 9.52 | 9.64 | .07 |
| .08 | 9.76 | 9.88 | 10.00 | 10.13 | 10.25 | 10.37 | 10.49 | 10.61 | 10.74 | 10.86 | .08 |
| .09 | 10.98 | 11.10 | 11.22 | 11.35 | 11.47 | 11.59 | 11.71 | 11.83 | 11.96 | 12.08 | .09 |

## CALCIUM METASILICATE (WOLLASTONITE), $CaO.SiO_2$. MOLECULAR WEIGHT, 116. ~~100~~

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .12 | .23 | .35 | .46 | .58 | .70 | .81 | .93 | 1.04 | .00 |
| .01 | 1.16 | 1.28 | 1.39 | 1.51 | 1.63 | 1.74 | 1.86 | 1.97 | 2.09 | 2.20 | .01 |
| .02 | 2.32 | 2.44 | 2.55 | 2.67 | 2.78 | 2.90 | 3.02 | 3.13 | 3.25 | 3.36 | .02 |
| .03 | 3.48 | 3.60 | 3.71 | 3.83 | 3.94 | 4.06 | 4.18 | 4.29 | 4.41 | 4.52 | .03 |
| .04 | 4.64 | 4.76 | 4.87 | 4.99 | 5.10 | 5.22 | 5.34 | 5.45 | 5.57 | 5.68 | .04 |
| .05 | 5.80 | 5.92 | 6.03 | 6.15 | 6.26 | 6.38 | 6.50 | 6.61 | 6.73 | 6.84 | .05 |
| .06 | 6.96 | 7.08 | 7.19 | 7.31 | 7.42 | 7.54 | 7.66 | 7.77 | 7.89 | 8.00 | .06 |
| .07 | 8.12 | 8.24 | 8.35 | 8.47 | 8.58 | 8.70 | 8.82 | 8.93 | 9.05 | 9.16 | .07 |
| .08 | 9.28 | 9.40 | 9.51 | 9.63 | 9.74 | 9.86 | 9.78 | 10.09 | 10.21 | 10.32 | .08 |
| .09 | 10.44 | 10.56 | 10.67 | 10.79 | 10.90 | 11.02 | 11.14 | 11.25 | 11.37 | 11.48 | .09 |
| .10 | 11.60 | 11.72 | 11.83 | 11.95 | 12.06 | 12.18 | 12.30 | 12.41 | 12.53 | 12.64 | .10 |
| .11 | 12.76 | 12.88 | 12.99 | 13.11 | 13.22 | 13.34 | 13.46 | 13.57 | 13.69 | 13.80 | .11 |
| .12 | 13.92 | 14.04 | 14.15 | 14.27 | 14.38 | 14.50 | 14.62 | 14.73 | 14.85 | 14.96 | .12 |
| .13 | 15.08 | 15.20 | 15.31 | 15.43 | 15.54 | 15.66 | 15.78 | 15.89 | 16.01 | 16.12 | .13 |
| .14 | 16.24 | 16.36 | 16.47 | 16.59 | 16.70 | 16.82 | 16.93 | 17.05 | 17.17 | 17.28 | .14 |
| .15 | 17.40 | 17.52 | 17.63 | 17.75 | 17.86 | 17.98 | 18.10 | 18.21 | 18.33 | 18.44 | .15 |
| .16 | 18.56 | 18.68 | 18.79 | 18.91 | 19.02 | 19.14 | 19.26 | 19.37 | 19.49 | 19.60 | .16 |
| .17 | 19.72 | 19.84 | 19.95 | 20.07 | 20.18 | 20.30 | 20.42 | 20.53 | 20.65 | 20.76 | .17 |
| .18 | 20.88 | 21.00 | 21.11 | 21.23 | 21.34 | 21.46 | 21.58 | 21.69 | 21.81 | 21.92 | .18 |
| .19 | 22.04 | 22.16 | 22.27 | 22.39 | 22.50 | 22.62 | 22.74 | 22.85 | 22.97 | 23.08 | .19 |
| .20 | 23.20 | 23.32 | 23.43 | 23.55 | 23.66 | 23.78 | 23.90 | 24.01 | 24.13 | 24.24 | .20 |
| .21 | 24.36 | 24.48 | 24.59 | 24.71 | 24.82 | 24.94 | 25.06 | 25.17 | 25.29 | 25.40 | .21 |
| .22 | 25.52 | 25.64 | 25.75 | 25.87 | 25.98 | 26.10 | 26.22 | 26.33 | 26.45 | 26.56 | .22 |
| .23 | 26.68 | 26.80 | 26.91 | 27.03 | 27.14 | 27.26 | 27.38 | 27.49 | 27.61 | 27.72 | .23 |
| .24 | 27.84 | 27.96 | 28.07 | 28.19 | 28.30 | 28.42 | 28.54 | 28.65 | 28.77 | 28.88 | .24 |
| .25 | 29.00 | 29.12 | 29.23 | 29.35 | 29.46 | 29.58 | 29.70 | 29.81 | 29.93 | 30.04 | .25 |
| .26 | 30.16 | 30.28 | 30.39 | 30.51 | 30.63 | 30.74 | 30.86 | 30.97 | 31.09 | 31.20 | .26 |
| .27 | 31.32 | 31.44 | 31.55 | 31.67 | 31.78 | 31.90 | 32.02 | 32.13 | 32.25 | 32.36 | .27 |
| .28 | 32.48 | 32.60 | 32.71 | 32.83 | 32.94 | 33.06 | 33.18 | 33.29 | 33.41 | 33.52 | .28 |
| .29 | 33.64 | 33.76 | 33.87 | 33.99 | 34.10 | 34.22 | 34.34 | 34.45 | 34.57 | 34.68 | .29 |
| .30 | 34.80 | 34.92 | 35.03 | 35.15 | 35.26 | 35.38 | 35.50 | 35.61 | 35.73 | 35.84 | .30 |
| .31 | 35.96 | 36.08 | 36.19 | 36.31 | 36.42 | 36.54 | 36.66 | 36.77 | 36.89 | 37.00 | .31 |
| .32 | 37.12 | 37.24 | 37.35 | 37.47 | 37.58 | 37.70 | 37.82 | 37.93 | 38.05 | 38.16 | .32 |
| .33 | 38.28 | 38.40 | 38.51 | 38.63 | 38.74 | 38.86 | 38.78 | 39.09 | 39.21 | 39.32 | .33 |
| .34 | 39.44 | 39.56 | 39.67 | 39.79 | 39.90 | 40.02 | 40.14 | 40.25 | 40.37 | 40.48 | .34 |
| .35 | 40.60 | 40.72 | 40.83 | 40.95 | 41.06 | 41.18 | 41.30 | 41.41 | 41.53 | 41.64 | .35 |
| .36 | 41.76 | 41.88 | 41.99 | 42.11 | 42.22 | 42.34 | 42.46 | 42.57 | 42.69 | 42.80 | .36 |
| .37 | 42.92 | 43.04 | 43.15 | 43.27 | 43.38 | 43.50 | 43.62 | 43.73 | 43.85 | 43.96 | .37 |
| .38 | 44.08 | 44.20 | 44.31 | 44.43 | 44.54 | 44.66 | 44.78 | 44.89 | 45.01 | 45.12 | .38 |
| .39 | 45.24 | 45.36 | 45.47 | 45.59 | 45.70 | 45.82 | 45.93 | 46.05 | 46.17 | 46.28 | .39 |

MAGNESIUM METASILICATE $MgO.SiO_2$. MOLECULAR WEIGHT, ~~100~~. 46

Multiply molecular proportion by 100.

IRON METASILICATE, $FeO.SiO_2$. MOLECULAR WEIGHT 132.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .13 | .26 | .40 | .53 | .66 | .79 | .92 | 1.06 | 1.19 | .00 |
| .01 | 1.32 | 1.45 | 1.58 | 1.72 | 1.85 | 1.98 | 2.11 | 2.24 | 2.38 | 2.51 | .01 |
| .02 | 2.64 | 2.77 | 2.90 | 3.04 | 3.17 | 3.30 | 3.43 | 3.56 | 3.70 | 3.83 | .02 |
| .03 | 3.96 | 4.09 | 4.22 | 4.36 | 4.49 | 4.62 | 4.75 | 4.88 | 5.02 | 5.15 | .03 |
| .04 | 5.28 | 5.41 | 5.54 | 5.68 | 5.81 | 5.94 | 6.07 | 6.20 | 6.34 | 6.47 | .04 |
| .05 | 6.60 | 6.73 | 6.86 | 7.00 | 7.13 | 7.26 | 7.39 | 7.52 | 7.66 | 7.79 | .05 |
| .06 | 7.92 | 8.05 | 8.18 | 8.32 | 8.45 | 8.58 | 8.71 | 8.84 | 8.98 | 9.11 | .06 |
| .07 | 9.24 | 9.37 | 9.50 | 9.64 | 9.77 | 9.90 | 10.03 | 10.16 | 10.30 | 10.43 | .07 |
| .08 | 10.56 | 10.69 | 10.82 | 10.96 | 11.09 | 11.22 | 11.35 | 11.48 | 11.62 | 11.75 | .08 |
| .09 | 11.88 | 12.01 | 12.14 | 12.28 | 12.41 | 12.54 | 12.67 | 12.80 | 12.94 | 13.07 | .09 |
| .10 | 13.20 | 13.33 | 13.46 | 13.60 | 13.73 | 13.86 | 13.99 | 14.12 | 14.26 | 14.39 | .10 |
| .11 | 14.52 | 14.65 | 14.78 | 14.92 | 15.05 | 15.18 | 15.31 | 15.44 | 15.58 | 15.71 | .11 |
| .12 | 15.84 | 15.97 | 16.10 | 16.24 | 16.37 | 16.50 | 16.63 | 16.76 | 16.90 | 17.03 | .12 |
| .13 | 17.16 | 17.29 | 17.42 | 17.56 | 17.69 | 17.82 | 17.95 | 18.08 | 18.22 | 18.35 | .13 |
| .14 | 18.48 | 18.61 | 18.74 | 18.88 | 19.01 | 19.14 | 19.27 | 19.40 | 19.54 | 19.67 | .14 |
| .15 | 19.80 | 19.93 | 20.06 | 20.20 | 20.33 | 20.46 | 20.59 | 20.72 | 20.86 | 20.99 | .15 |
| .16 | 21.12 | 21.25 | 21.38 | 21.52 | 21.65 | 21.78 | 21.91 | 22.04 | 22.18 | 22.31 | .16 |
| .17 | 22.44 | 22.57 | 22.70 | 22.84 | 22.97 | 23.10 | 23.23 | 23.36 | 23.50 | 23.63 | .17 |
| .18 | 23.76 | 23.89 | 24.02 | 24.16 | 24.29 | 24.42 | 24.55 | 24.68 | 24.82 | 24.95 | .18 |
| .19 | 25.08 | 25.21 | 25.34 | 25.48 | 25.61 | 25.74 | 25.87 | 26.00 | 26.14 | 26.27 | .19 |
| .20 | 26.40 | 26.53 | 26.66 | 26.80 | 26.93 | 27.06 | 27.19 | 27.32 | 27.46 | 27.59 | .20 |
| .21 | 27.72 | 27.85 | 27.98 | 28.12 | 28.25 | 28.38 | 28.51 | 28.64 | 28.78 | 28.91 | .21 |
| .22 | 29.04 | 29.17 | 29.30 | 29.44 | 29.57 | 29.70 | 29.83 | 29.96 | 30.10 | 30.23 | .22 |
| .23 | 30.36 | 30.49 | 30.62 | 30.76 | 30.89 | 31.02 | 31.15 | 31.28 | 31.42 | 31.55 | .23 |
| .24 | 31.68 | 31.81 | 31.94 | 32.08 | 32.21 | 32.34 | 32.47 | 32.60 | 32.74 | 32.87 | .24 |
| .25 | 33.00 | 33.13 | 33.26 | 33.40 | 33.53 | 33.66 | 33.79 | 33.92 | 34.06 | 34.19 | .25 |
| .26 | 34.32 | 34.45 | 34.58 | 34.72 | 34.85 | 34.98 | 35.11 | 35.24 | 35.38 | 35.51 | .26 |
| .27 | 35.64 | 35.77 | 35.90 | 36.04 | 36.17 | 36.30 | 36.43 | 36.56 | 36.70 | 36.83 | .27 |
| .28 | 36.96 | 37.09 | 37.22 | 37.36 | 37.49 | 37.62 | 37.75 | 37.88 | 38.02 | 38.15 | .28 |
| .29 | 38.28 | 38.41 | 38.54 | 38.68 | 38.81 | 38.94 | 39.07 | 39.20 | 39.34 | 39.47 | .29 |
| .30 | 39.60 | 39.73 | 39.86 | 40.00 | 40.13 | 40.26 | 40.39 | 40.52 | 40.66 | 40.79 | .30 |
| .31 | 40.92 | 41.05 | 41.18 | 41.32 | 41.45 | 41.58 | 41.71 | 41.84 | 41.98 | 42.11 | .31 |
| .32 | 42.24 | 42.37 | 42.50 | 42.64 | 42.77 | 42.90 | 43.03 | 43.16 | 43.30 | 43.43 | .32 |
| .33 | 43.56 | 43.69 | 43.82 | 43.96 | 44.09 | 44.22 | 44.35 | 44.48 | 44.62 | 44.75 | .33 |
| .34 | 44.88 | 45.01 | 45.14 | 45.28 | 45.41 | 45.54 | 45.67 | 45.80 | 45.94 | 46.07 | .34 |
| .35 | 46.20 | 46.33 | 46.46 | 46.60 | 46.73 | 46.86 | 46.99 | 47.12 | 47.26 | 47.30 | .35 |
| .36 | 47.52 | 47.65 | 47.78 | 47.92 | 48.05 | 48.18 | 48.21 | 48.44 | 48.58 | 48.71 | .36 |
| .37 | 48.84 | 48.97 | 49.10 | 49.24 | 49.37 | 49.50 | 49.63 | 49.76 | 49.90 | 50.03 | .37 |
| .38 | 50.16 | 50.29 | 50.42 | 50.56 | 50.69 | 50.82 | 50.95 | 51.08 | 51.22 | 51.35 | .38 |
| .39 | 51.48 | 51.61 | 51.74 | 51.88 | 52.01 | 52.14 | 52.27 | 52.40 | 52.54 | 52.67 | .39 |

## MAGNESIUM-ORTHOSILICATE (FORSTERITE), $2MgO.SiO_2$. MOLECULAR WEIGHT, 140.

(Unit of calculation is one-half molecular proportion of MgO)

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .14 | .28 | .42 | .56 | .70 | .84 | .98 | 1.12 | 1.26 | .00 |
| .01 | 1.40 | 1.54 | 1.68 | 1.82 | 1.96 | 2.10 | 2.24 | 2.38 | 2.52 | 2.66 | .01 |
| .02 | 2.80 | 2.94 | 3.08 | 3.22 | 3.36 | 3.50 | 3.64 | 3.78 | 3.92 | 4.06 | .02 |
| .03 | 4.20 | 4.34 | 4.48 | 4.62 | 4.76 | 4.90 | 5.04 | 5.18 | 5.32 | 5.46 | .03 |
| .04 | 5.60 | 5.74 | 5.88 | 6.02 | 6.16 | 6.30 | 6.44 | 6.58 | 6.72 | 6.86 | .04 |
| .05 | 7.00 | 7.14 | 7.28 | 7.42 | 7.56 | 7.70 | 7.84 | 7.98 | 8.12 | 8.26 | .05 |
| .06 | 8.40 | 8.54 | 8.68 | 8.82 | 8.96 | 9.10 | 9.24 | 9.38 | 9.52 | 9.66 | .06 |
| .07 | 9.80 | 9.94 | 10.08 | 10.22 | 10.36 | 10.50 | 10.64 | 10.78 | 10.92 | 11.06 | .07 |
| .08 | 11.20 | 11.34 | 11.48 | 11.62 | 11.76 | 11.90 | 12.04 | 12.18 | 12.32 | 12.46 | .08 |
| .09 | 12.60 | 12.74 | 12.88 | 13.02 | 13.16 | 13.30 | 13.44 | 13.58 | 13.72 | 13.86 | .09 |
| .10 | 14.00 | 14.14 | 14.28 | 14.42 | 14.56 | 14.70 | 14.84 | 14.98 | 15.12 | 15.26 | .10 |
| .11 | 15.40 | 15.54 | 15.68 | 15.82 | 15.96 | 16.10 | 16.24 | 16.38 | 16.52 | 16.66 | .11 |
| .12 | 16.80 | 16.94 | 17.08 | 17.22 | 17.36 | 17.50 | 17.64 | 17.78 | 17.92 | 18.06 | .12 |
| .13 | 18.20 | 18.34 | 18.48 | 18.62 | 18.76 | 18.90 | 19.04 | 19.18 | 19.32 | 19.46 | .13 |
| .14 | 19.60 | 19.74 | 19.88 | 20.02 | 20.16 | 20.30 | 20.44 | 20.58 | 20.72 | 20.86 | .14 |
| .15 | 21.00 | 21.14 | 21.28 | 21.42 | 21.56 | 21.70 | 21.84 | 21.98 | 22.12 | 22.26 | .15 |
| .16 | 22.40 | 22.54 | 22.68 | 22.82 | 22.96 | 23.10 | 23.24 | 23.38 | 23.52 | 23.66 | .16 |
| .17 | 23.80 | 23.94 | 24.08 | 24.22 | 24.36 | 24.50 | 24.64 | 24.78 | 24.92 | 25.06 | .17 |
| .18 | 25.20 | 25.34 | 25.48 | 25.62 | 25.76 | 25.90 | 26.04 | 26.18 | 26.32 | 26.46 | .18 |
| .19 | 26.60 | 26.74 | 26.88 | 27.02 | 27.16 | 27.30 | 27.44 | 27.58 | 27.72 | 27.86 | .19 |
| .20 | 28.00 | 28.14 | 28.28 | 28.42 | 28.56 | 28.70 | 28.84 | 28.98 | 29.12 | 29.26 | .20 |
| .21 | 29.40 | 29.54 | 29.68 | 29.82 | 29.96 | 30.10 | 30.24 | 30.38 | 30.52 | 30.66 | .21 |
| .22 | 30.80 | 30.94 | 31.08 | 31.22 | 31.36 | 31.50 | 31.64 | 31.78 | 31.92 | 32.06 | .22 |
| .23 | 32.20 | 32.34 | 32.48 | 32.62 | 32.76 | 32.90 | 33.04 | 33.18 | 33.32 | 33.46 | .23 |
| .24 | 33.60 | 33.74 | 33.88 | 34.02 | 34.16 | 34.30 | 34.44 | 34.58 | 34.72 | 34.86 | .24 |
| .25 | 35.00 | 35.14 | 35.28 | 35.42 | 35.56 | 35.70 | 35.84 | 35.98 | 36.12 | 36.26 | .25 |
| .26 | 36.40 | 36.54 | 36.68 | 36.82 | 36.96 | 37.10 | 37.24 | 37.38 | 37.52 | 37.66 | .26 |
| .27 | 37.80 | 37.94 | 38.08 | 38.22 | 38.36 | 38.50 | 38.64 | 38.78 | 38.92 | 39.06 | .27 |
| .28 | 39.20 | 39.34 | 39.48 | 39.62 | 39.76 | 39.90 | 40.04 | 40.18 | 40.32 | 40.46 | .28 |
| .29 | 40.60 | 40.74 | 40.88 | 41.02 | 41.16 | 41.30 | 41.44 | 41.58 | 41.72 | 41.86 | .29 |
| .30 | 42.00 | 42.14 | 42.28 | 42.42 | 42.56 | 42.70 | 42.84 | 42.98 | 43.12 | 43.26 | .30 |
| .31 | 43.40 | 43.54 | 43.68 | 43.82 | 43.96 | 44.10 | 44.24 | 44.38 | 44.52 | 44.66 | .31 |
| .32 | 44.80 | 44.94 | 45.08 | 45.22 | 45.36 | 45.50 | 45.64 | 45.78 | 45.92 | 46.06 | .32 |
| .33 | 46.20 | 46.34 | 46.48 | 46.62 | 46.76 | 46.90 | 47.04 | 47.18 | 47.32 | 47.46 | .33 |
| .34 | 47.60 | 47.74 | 47.88 | 48.02 | 48.16 | 48.30 | 48.44 | 48.58 | 48.72 | 48.86 | .34 |
| .35 | 49.00 | 49.14 | 49.28 | 49.42 | 49.56 | 49.70 | 49.84 | 49.98 | 50.12 | 50.26 | .35 |
| .36 | 50.40 | 50.54 | 50.68 | 50.82 | 50.96 | 51.10 | 51.24 | 51.38 | 51.52 | 51.66 | .36 |
| .37 | 51.80 | 51.94 | 52.08 | 52.22 | 52.36 | 52.50 | 52.64 | 52.78 | 52.92 | 53.06 | .37 |
| .38 | 53.20 | 53.34 | 53.48 | 53.62 | 53.76 | 53.90 | 54.04 | 54.18 | 54.32 | 54.46 | .38 |
| .39 | 54.60 | 54.74 | 54.88 | 55.02 | 55.16 | 55.30 | 55.44 | 55.58 | 55.72 | 55.86 | .39 |

## IRON ORTHOSILICATE (FAYALITE), $2FeO.SiO_2$. MOLECULAR WEIGHT, 204.

(Unit of calculation is one-half molecular proportion of FeO)

| Mol. | 000. | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .20 | .41 | .61 | .82 | 1.02 | 1.22 | 1.43 | 1.63 | 1.84 | .00 |
| .01 | 2.04 | 2.24 | 2.45 | 2.65 | 2.86 | 3.06 | 3.26 | 3.47 | 3.67 | 3.88 | .01 |
| .02 | 4.08 | 4.28 | 4.49 | 4.69 | 4.90 | 5.10 | 5.30 | 5.51 | 5.71 | 5.92 | .02 |
| .03 | 6.12 | 6.32 | 6.53 | 6.73 | 6.94 | 7.14 | 7.34 | 7.55 | 7.75 | 7.96 | .03 |
| .04 | 8.16 | 8.36 | 8.57 | 8.77 | 8.98 | 9.18 | 9.38 | 9.59 | 9.79 | 10.00 | .04 |
| .05 | 10.20 | 10.40 | 10.61 | 10.81 | 11.02 | 11.22 | 11.42 | 11.63 | 11.83 | 12.04 | .05 |
| .06 | 12.24 | 12.44 | 12.65 | 12.85 | 13.06 | 13.26 | 13.46 | 13.67 | 13.87 | 14.08 | .06 |
| .07 | 14.28 | 14.48 | 14.69 | 14.89 | 15.10 | 15.30 | 15.50 | 15.71 | 15.91 | 16.12 | .07 |
| .08 | 16.32 | 16.52 | 16.72 | 16.93 | 17.14 | 17.34 | 17.54 | 17.75 | 17.95 | 18.16 | .08 |
| .09 | 18.36 | 18.56 | 18.77 | 18.97 | 19.18 | 19.38 | 19.58 | 19.79 | 19.99 | 20.20 | .09 |
| .10 | 20.40 | 20.60 | 20.81 | 21.01 | 21.22 | 21.42 | 21.62 | 21.83 | 22.03 | 22.24 | .10 |
| .11 | 22.44 | 22.64 | 22.85 | 23.05 | 23.26 | 23.46 | 23.66 | 23.87 | 24.07 | 24.28 | .11 |
| .12 | 24.48 | 24.68 | 24.89 | 25.09 | 25.30 | 25.50 | 25.70 | 25.91 | 26.11 | 26.32 | .12 |
| .13 | 26.52 | 26.72 | 26.93 | 27.13 | 27.34 | 27.54 | 27.74 | 27.95 | 28.15 | 28.36 | .13 |
| .14 | 28.56 | 28.76 | 28.97 | 29.17 | 29.38 | 29.58 | 29.78 | 29.99 | 30.19 | 30.40 | .14 |
| .15 | 30.60 | 30.80 | 31.01 | 31.21 | 31.42 | 31.62 | 31.82 | 32.03 | 32.23 | 32.44 | .15 |
| .16 | 32.64 | 32.84 | 33.05 | 33.25 | 33.46 | 33.66 | 33.86 | 34.07 | 34.27 | 34.48 | .16 |
| .17 | 34.68 | 34.88 | 35.11 | 35.31 | 35.50 | 35.70 | 35.90 | 36.11 | 36.31 | 36.52 | .17 |
| .18 | 36.72 | 36.92 | 37.15 | 37.35 | 37.54 | 37.74 | 37.94 | 38.15 | 38.35 | 38.56 | .18 |
| .19 | 38.76 | 38.96 | 39.19 | 39.39 | 39.58 | 39.78 | 39.98 | 40.19 | 40.39 | 40.60 | .19 |

## AKERMANITE, $4CaO.3SiO_2$. MOLECULAR WEIGHT, 404.

(Unit of calculation is one-fourth molecular proportion of CaO)

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .40 | .81 | 1.21 | 1.62 | 2.02 | 2.42 | 2.83 | 3.23 | 3.64 | .00 |
| .01 | 4.04 | 4.44 | 4.85 | 5.25 | 5.66 | 6.06 | 6.46 | 6.87 | 7.27 | 7.68 | .01 |
| .02 | 8.08 | 8.48 | 8.89 | 9.29 | 9.70 | 10.10 | 10.50 | 10.91 | 11.31 | 11.72 | .02 |
| .03 | 12.12 | 12.52 | 12.93 | 13.33 | 13.74 | 14.14 | 14.54 | 14.95 | 15.35 | 15.76 | .03 |
| .04 | 16.16 | 16.56 | 16.97 | 17.37 | 17.78 | 18.18 | 18.58 | 18.99 | 19.39 | 19.80 | .04 |
| .05 | 20.20 | 20.60 | 21.01 | 21.41 | 21.82 | 22.22 | 22.62 | 23.03 | 23.43 | 23.84 | .05 |
| .06 | 24.24 | 24.64 | 25.05 | 25.45 | 25.86 | 26.26 | 26.66 | 27.07 | 27.47 | 27.88 | .06 |
| .07 | 28.28 | 28.68 | 29.09 | 29.49 | 29.90 | 30.30 | 30.70 | 31.11 | 31.51 | 31.92 | .07 |
| .08 | 32.32 | 32.72 | 33.13 | 33.53 | 33.94 | 34.34 | 34.74 | 35.15 | 35.55 | 35.96 | .08 |
| .09 | 36.36 | 36.76 | 37.17 | 37.57 | 37.98 | 38.38 | 38.78 | 39.19 | 39.59 | 40.00 | .09 |

### MAGNETITE, $FeO.Fe_2O_3$. MOLECULAR WEIGHT, 232.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .23 | .46 | .70 | .93 | 1.16 | 1.39 | 1.62 | 1.86 | 2.09 | .00 |
| .01 | 2.32 | 2.55 | 2.78 | 3.02 | 3.25 | 3.48 | 3.71 | 3.94 | 4.18 | 4.41 | .01 |
| .02 | 4.64 | 4.87 | 5.10 | 5.34 | 5.57 | 5.80 | 6.03 | 6.26 | 6.50 | 6.73 | .02 |
| .03 | 6.96 | 7.19 | 7.42 | 7.66 | 7.89 | 8.12 | 8.35 | 8.58 | 8.82 | 9.05 | .03 |
| .04 | 9.28 | 9.51 | 9.74 | 9.98 | 10.21 | 10.44 | 10.67 | 10.90 | 11.14 | 11.37 | .04 |
| .05 | 11.60 | 11.83 | 12.06 | 12.30 | 12.53 | 12.76 | 12.99 | 13.22 | 13.46 | 13.69 | .05 |
| .06 | 13.92 | 14.15 | 14.38 | 14.62 | 14.85 | 15.08 | 15.31 | 15.54 | 15.78 | 16.01 | .06 |
| .07 | 16.24 | 16.47 | 16.70 | 16.94 | 17.17 | 17.40 | 17.63 | 17.86 | 18.10 | 18.33 | .07 |
| .08 | 18.56 | 18.79 | 19.02 | 19.26 | 19.49 | 19.72 | 19.95 | 20.18 | 20.42 | 20.65 | .08 |
| .09 | 20.88 | 21.11 | 21.34 | 21.58 | 21.81 | 22.04 | 22.27 | 22.50 | 22.74 | 22.97 | .09 |

### HEMATITE, $Fe_2O_3$. MOLECULAR WEIGHT, 160.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .16 | .32 | .48 | .64 | .80 | .96 | 1.12 | 1.28 | 1.44 | .00 |
| .01 | 1.60 | 1.76 | 1.92 | 2.08 | 2.24 | 2.40 | 2.56 | 2.72 | 2.88 | 3.04 | .01 |
| .02 | 3.20 | 3.36 | 3.52 | 3.68 | 3.84 | 4.00 | 4.16 | 4.32 | 4.48 | 4.64 | .02 |
| .03 | 4.80 | 4.96 | 5.12 | 5.28 | 5.44 | 5.60 | 5.76 | 5.92 | 6.08 | 6.24 | .03 |
| .04 | 6.40 | 6.56 | 6.72 | 6.88 | 7.04 | 7.20 | 7.36 | 7.52 | 7.68 | 7.84 | .04 |

### ILMENITE, $FeO.TiO_2$. MOLECULAR WEIGHT, 152.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .15 | .30 | .46 | .61 | .76 | .91 | 1.06 | 1.22 | 1.37 | .00 |
| .01 | 1.52 | 1.67 | 1.82 | 1.98 | 2.13 | 2.28 | 2.43 | 2.58 | 2.74 | 2.89 | .01 |
| .02 | 3.04 | 3.19 | 3.34 | 3.50 | 3.65 | 3.80 | 3.95 | 4.10 | 4.26 | 4.41 | .02 |
| .03 | 4.56 | 4.71 | 4.86 | 5.02 | 5.17 | 5.32 | 5.47 | 5.62 | 5.78 | 5.93 | .03 |
| .04 | 6.08 | 6.23 | 6.38 | 6.54 | 6.69 | 6.84 | 6.99 | 7.14 | 7.30 | 7.45 | .04 |
| .05 | 7.60 | 7.75 | 7.90 | 8.06 | 8.21 | 8.36 | 8.51 | 8.66 | 8.82 | 8.97 | .05 |
| .06 | 9.12 | 9.27 | 9.42 | 9.58 | 9.73 | 9.88 | 10.03 | 10.18 | 10.34 | 10.49 | .06 |
| .07 | 10.64 | 10.79 | 10.94 | 11.10 | 11.25 | 11.40 | 11.55 | 11.70 | 11.86 | 12.01 | .07 |
| .08 | 12.16 | 12.31 | 12.46 | 12.62 | 12.77 | 12.92 | 13.07 | 13.22 | 13.38 | 13.53 | .08 |
| .09 | 13.68 | 13.83 | 13.98 | 14.14 | 14.29 | 14.44 | 14.59 | 14.74 | 14.90 | 15.05 | .09 |

### PEROFSKITE, $CaO.TiO_2$. MOLECULAR WEIGHT, 136.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .14 | .27 | .41 | .54 | .68 | .82 | .95 | 1.09 | 1.22 | .00 |
| .01 | 1.36 | 1.50 | 1.63 | 1.77 | 1.90 | 2.04 | 2.18 | 2.31 | 2.45 | 2.58 | .01 |
| .02 | 2.72 | 2.86 | 2.99 | 3.13 | 3.26 | 3.40 | 3.54 | 3.67 | 3.81 | 3.94 | .02 |
| .03 | 4.08 | 4.22 | 4.35 | 4.49 | 4.62 | 4.76 | 4.90 | 5.03 | 5.17 | 5.30 | .03 |
| .04 | 5.44 | 5.58 | 5.71 | 5.85 | 5.98 | 6.12 | 6.26 | 6.39 | 6.53 | 6.66 | .04 |
| .05 | 6.80 | 6.94 | 7.07 | 7.21 | 7.34 | 7.48 | 7.62 | 7.75 | 7.89 | 8.02 | .05 |
| .06 | 8.16 | 8.30 | 8.43 | 8.57 | 8.70 | 8.84 | 8.98 | 9.11 | 9.25 | 9.38 | .06 |
| .07 | 9.52 | 9.66 | 9.79 | 9.93 | 10.06 | 10.20 | 10.34 | 10.47 | 10.61 | 10.74 | .07 |
| .08 | 10.88 | 11.02 | 11.15 | 11.29 | 11.42 | 11.56 | 11.70 | 11.83 | 11.97 | 12.10 | .08 |
| .09 | 12.24 | 12.38 | 12.51 | 12.65 | 12.78 | 12.92 | 13.06 | 13.19 | 13.33 | 13.46 | .09 |

### TITANITE, $CaO.TiO_2.SiO_2$. MOLECULAR WEIGHT, 196.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .20 | .39 | .59 | .78 | .98 | 1.18 | 1.37 | 1.57 | 1.76 | .00 |
| .01 | 1.96 | 2.16 | 2.35 | 2.55 | 2.74 | 2.94 | 3.14 | 3.33 | 3.53 | 3.72 | .01 |
| .02 | 3.92 | 4.12 | 4.31 | 4.51 | 4.70 | 4.90 | 5.10 | 5.29 | 5.49 | 5.68 | .02 |
| .03 | 5.88 | 6.08 | 6.27 | 6.47 | 6.66 | 6.86 | 7.06 | 7.25 | 7.45 | 7.64 | .03 |
| .04 | 7.84 | 8.04 | 8.23 | 8.43 | 8.62 | 8.82 | 9.02 | 9.21 | 9.41 | 9.60 | .04 |
| .05 | 9.80 | 10.00 | 10.19 | 10.39 | 10.58 | 10.78 | 10.98 | 11.17 | 11.37 | 11.56 | .05 |
| .06 | 11.76 | 11.96 | 12.15 | 12.35 | 12.54 | 12.74 | 12.94 | 13.13 | 13.33 | 13.52 | .06 |
| .07 | 13.72 | 13.92 | 14.11 | 14.31 | 14.50 | 14.70 | 14.90 | 15.09 | 15.29 | 15.48 | .07 |
| .08 | 15.68 | 15.88 | 16.07 | 16.27 | 16.46 | 16.66 | 16.86 | 17.05 | 17.25 | 17.44 | .08 |
| .09 | 17.64 | 17.84 | 18.03 | 18.23 | 18.42 | 18.62 | 18.82 | 19.01 | 19.21 | 19.40 | .09 |

### APATITE, $3CaO.P_2O_5 + \frac{CaF_2}{3}$. MOLECULAR WEIGHT, 336.

(Unit of calculation is molecular proportion of $P_2O_5$)

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .34 | .67 | 1.01 | 1.34 | 1.68 | 2.02 | 2.35 | 2.69 | 3.02 | .00 |
| .01 | 3.36 | 3.70 | 4.03 | 4.37 | 4.70 | 5.04 | 5.38 | 5.71 | 6.05 | 6.38 | .01 |
| .02 | 6.72 | 7.06 | 7.39 | 7.73 | 8.06 | 8.40 | 8.74 | 9.07 | 9.41 | 9.74 | .02 |
| .03 | 10.08 | 10.42 | 10.75 | 11.09 | 11.42 | 11.76 | 12.10 | 12.43 | 12.77 | 13.10 | .03 |
| .04 | 13.44 | 13.78 | 14.11 | 14.45 | 14.78 | 15.12 | 15.46 | 15.79 | 16.13 | 16.46 | .04 |

### FLUORITE, $CaF_2$. MOLECULAR WEIGHT, 78.

| Mol. | .000 | .001 | .002 | .003 | .004 | .005 | .006 | .007 | .008 | .009 | Mol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .00 | .00 | .07 | .16 | .23 | .31 | .39 | .47 | .55 | .62 | .70 | .00 |
| .01 | .78 | .86 | .94 | 1.01 | 1.09 | 1.17 | 1.25 | 1.33 | 1.40 | 1.48 | .01 |
| .02 | 1.56 | 1.64 | 1.72 | 1.79 | 1.87 | 1.95 | 2.03 | 2.11 | 2.18 | 2.26 | .02 |
| .03 | 2.34 | 2.42 | 2.50 | 2.57 | 2.65 | 2.73 | 2.81 | 2.89 | 2.96 | 3.04 | .03 |
| .04 | 3.12 | 3.20 | 3.28 | 3.35 | 3.43 | 3.51 | 3.59 | 3.67 | 3.74 | 3.82 | .04 |
| .05 | 3.90 | 3.98 | 4.06 | 4.13 | 4.21 | 4.29 | 4.37 | 4.45 | 4.52 | 4.60 | .05 |
| .06 | 4.68 | 4.76 | 4.84 | 4.91 | 4.99 | 5.07 | 5.15 | 5.23 | 5.30 | 5.38 | .06 |
| .07 | 5.46 | 5.54 | 5.62 | 5.69 | 5.77 | 5.85 | 5.93 | 6.01 | 6.08 | 6.16 | .07 |
| .08 | 6.24 | 6.32 | 6.40 | 6.47 | 6.55 | 6.63 | 6.71 | 6.79 | 6.86 | 6.94 | .08 |
| .09 | 7.02 | 7.10 | 7.18 | 7.25 | 7.33 | 7.41 | 7.49 | 7.57 | 7.64 | 7.72 | .09 |

### CHEMICAL COMPOSITION OF THE THEORETICAL MOLECULES[1] OF THE COMMONER ROCK-MAKING MINERALS WITH CONSTANT COMPOSITION.

| | $SiO_2$ | $ZrO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Cl | $SO_3$ | $H_2O$ |
|---|---|---|---|---|---|---|---|---|---|
| Quartz | 100.0 | .... | .... | .... | .... | .... | .... | .... | .... |
| Zircon | 32.8 | 67.2 | .... | .... | .... | .... | .... | .... | .... |
| Corundum | .... | .... | 100.0 | .... | .... | .... | .... | .... | .... |
| Orthoclase | 64.7 | .... | 18.4 | 16.9 | .... | .... | .... | .... | .... |
| Albite | 68.7 | .... | 19.5 | .... | 11.8 | .... | .... | .... | .... |
| Anorthite | 43.2 | .... | 36.7 | .... | .... | 20.1 | .... | .... | .... |
| Leucite | 55.0 | .... | 23.5 | 21.5 | .... | ... | .... | .... | .... |
| Analcite | 54.5 | .... | 23.2 | .... | 14.1 | .... | .... | .... | 8.2 |
| Nephelite[2] | 42.3 | .... | 35.9 | .... | 21.8 | .... | .... | .... | .... |
| Sodalite | 37.2 | .... | 31.6 | .... | 25.6 | .... | 7.3 | .... | .... |
| Noselite | 31.7 | .... | 26.9 | .... | 27.3 | .... | .... | 14.1 | .... |
| Hauynite | 32.0 | .... | 27.2 | .... | 16.6 | 10.0 | .... | 14.2 | .... |
| Muscovite[3] | 45.2 | .... | 38.5 | 11.8 | .... | .... | .... | .... | 4.5 |

| | $SiO_2$ | $TiO_2$ | CaO | FeO | $Fe_2O_3$ | S | $P_2O_5$ | F | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Titanite | 30.6 | 40.8 | 28.6 | .... | .... | .... | .... | .... | .... |
| Rutile | .... | 100.0 | .... | .... | .... | .... | .... | .... | .... |
| Perofskite | .... | 58.9 | 41.1 | .... | .... | .... | .... | .... | .... |
| Ilmenite | .... | 52.7 | .... | 47.3 | .... | .... | .... | .... | .... |
| Magnetite | .... | .... | .... | 31.0 | 69.0 | .... | .... | .... | .... |
| Hematite | .... | .... | .... | .... | 100.0 | .... | .... | .... | .... |
| Pyrite | .... | .... | .... | Fe<br>46.6 | .... | 52.4 | .... | .... | .... |
| Apatite | .... | .... | 55.5 | .... | .... | .... | 42.3 | 3.8 | .... |
| Fluorite | .... | .... | Ca<br>51.1 | .... | .... | .... | .... | 48.9 | .... |
| Calcite | .... | .... | 56.0 | .... | .... | .... | .... | .... | 44.0 |

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[1] *Dana's System of Mineralogy, 6th Ed.* [2] Free from $K_2O$. [3] H : K :: 2 : 1.

# GLOSSARY.

## A.

**Abnormative.** Not normative. Applied to minerals other than those that make up the norm of a rock (p. 149).

**Abnormative mode.** A mode in which abnormative minerals are present in notable amount, so that the rock cannot be classified directly from the minerals actually present, without consideration of the mutual changes involved in the diverse crystallization of the various minerals possible.

**Absarokose.** Dopotassic Subrang (2) of camptonase, the alkalicalcic Rang (3) of gallare, the perfelic Order (5) of salfemane, Class III. From absarokite (Iddings, *Jour. Geol.*, III. 938, 1895, anal. 3 and 5).

**Actual mineral composition.** The composition of a rock in terms of the minerals actually present, expressed quantitatively.

**Adamellose.** Sodipotassic Subrang (2) of dacase, the domalkalic Rang (2) of austrare, the quardofelic Order (4) of dosalane, Class II. From adamellite (Cathrein, *Neu. Jb.* 1890, 1. p. 74).

**Adirondackare.** Domitic Order (4) of dofemane, Class IV. From Adirondack Mountains, New York.

**Adirondackase.** Permirlic Rang (1) of adirondackore.

**Adirondackiase.** Permiric Section (1) of adirondackase.

**Adirondackore.** Dohemic Suborder (2) of adirondackare.

**Akerose.** Dosodic Subrang (4) of monzonase, the domalkalic Rang (2) of germanare, the perfelic Order (5) of dosalane, Class II. From akerite (Brögger, *Zeit. Kryst.* XVI, 45, 1890, anal. on p. 46).

**——al.** Suffix to indicate type (p. 179).

**Alaskase.** Peralkalic Rang (1) of columbare, the quarfelic Order (3) of persalane, Class I. From alaskite (Spurr, *Am. Geol.* XXV, 229. 1900).

**Alaskose.** Sodipotassic Subrang (3) of alaskase.

**Albanase.** Domalkalic Rang (2) of bohemare, the dolenic Order (8) of salfemane, Class III. From leucitite of Capo di Bove, Alban Hills, Italy (Washington, *Am. Jour. Sci.*, IX, p. 53, 1900).

**Albanose.** Dopotassic Subrang (2) of albanase.

**Alfer.** Term mnemonic of the aluminous ferromagnesian and calcic rock-making minerals, including augite, hornblende, mica, garnet, melilite, tourmaline, spinel, etc. (p. 116).

**Alferfemphyri.** Microscopically porphyritic, with both femic and alferric phenocrysts (p. 173).

**Alferfemphyric.** Having the phenocrysts both of femic and alferric minerals (p. 173).

**Alferfemphyro.** Megascopically porphyritic, with both femic and alferric phenocrysts (p. 173).

**Alferphyri.** Microscopically porphyritic, with alferric phenocrysts (p. 173).

**Alferphyric.** Having alferric phenocrysts (p. 173).

**Alferphyro.** Megascopically porphyritic, with alferric phenocrysts (p. 173).

**Alferric.** Having the characteristics of, or belonging to, the group of aluminous ferromagnesian and calcic silicates (p. 116).

**Alferric abnormative mode.** An abnormative mode in which alferric minerals are present in notable amount (p. 150).

**Alfersalphyri.** Microscopically porphyritic, with both salic and alferric phenocrysts (p. 173).

**Alfersalphyric.** Having the phenocrysts both of salic and alferric minerals (p. 173).

**Alfersalphyro.** Megascopically porphyritic, with both salic and alferric phenocrysts (p. 173).

**Alkalicalcic.** Having salic alkalies and salic lime present in equal or nearly equal amounts. $\frac{K_2O'+Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$ (p. 135).

**Alkalimirlic.** Having femic alkalies and magnesia, ferrous iron and femic lime in equal or nearly equal amounts. $\frac{MgO+FeO+CaO'}{K_2O'+Na_2O'} < \frac{5}{3} > \frac{3}{5}$ (p. 136).

**Almerase.** Alkalicalcic Rang (3) of hispanare, the quarfelic Order (3) of dosalane, Class II. From cordierite-andesite of Cabo da Gata, Almeria Province, Spain (Osann, *Zeit. deut. geol. Ges.*, XL, 701, 1888).

**Almerose.** Sodipotassic Subrang (3) of almerase.

**Alsbachase.** Domalkalic Rang (2) of columbare, the quarfelic Order (3) of persalane, Class I. From alsbachite (Chelius, *Not. Blatt. Ver. Erdk.*, Darmstadt, (4) III, 8, 1892).

**Alsbachose.** Dosodic Subrang (4) of alsbachase.

**Amadorose.** Persodic Subrang (5) of coloradase, the alkalicalcic Rang (3) of britannare, the quardofelic Order (4) of persalane, Class I. From quartz-diorite of Amador County, Cal. (Turner, *17th Ann. Rep. U. S. G. S.*, I, 702, 1896).

**Amiatose.** Sodipotassic Subrang (3) of coloradase, the alkalicalcic Rang (3) of britannare, the quardofelic Order (4) of persalane, Class I. From Mt. Amiata, Tuscany (J. F. Williams, *Neu. Jb.* B. Bd., V, 208–210, 1887).

**Andase.** Alkalicalcic Rang (3) of germanare, the perfelic Order (5) of dosalane, Class II. From andesite of the Andes.

**Andose.** Dosodic Subrang (4) of andase.

——**ane.** Suffix applied to names of Classes (p. 164).

**Aphanite.** A rock wholly, or in part, aphanitic.

**Aphanitic.** Not apparent to the unaided eye (megascopically) whether crystalline or not (p. 155).

**Aphanophyre.** A porphyry with aphanitic groundmass.

**Aphyri.** Microscopically non-porphyritic or aphyric (p. 173).

**Aphyric.** Non-porphyritic (p. 173).

**Aphyro.** Megascopically non-porphyritic or aphyric (p. 173).

——**are.** Suffix applied to names of Orders (p. 164).

**Argeinose.** Domagnesic Subrang (2) of lherziase, the permiric Section (1) of lherzase, the permirlic Rang (1) of pyreniare, the perolic Section (5) of hungarare, the perpolic Order (1) of dofemane, Class IV. From peridotite of Argein, Pyrenees Mts. (Lacroix, *C. R. VIII, Cong. Géol. Int.*, p. 833, 1901).

**Arkansose.** Sodipotassic Subrang (3) of urtase, the peralkalic Rang (1) of lappare, the perlenic Order (9) of dosalane, Class II. From arkite, from Arkansas (Washington, *Jour. Geol.*, IX, 615, 1901. anal on p. 616).

**——ase.** Suffix applied to names of Rangs (p. 164).

**——ate.** Suffix applied to names of Grads (p. 164).

**Atlantare.** Quarfelic Order (3) of salfemane, Class III. From Atlantic Ocean.

**Augite-leucophyre.** Leucophyre with augite phenocrysts.

**Augite-melaphyre.** Melaphyre with augite phenocrysts.

**Augitophyre.** Prophyry with augite phenocrysts.

**Austrare.** Quardofelic Order (4) of dosalane, Class II. From Austria.

**Auvergnase.** Docalcic Rang (4) of gallare, the perfelic Order (5) of salfemane, Class III. From basalts of Auvergne (Anal. v. Lasaulx, *Neu. Jb.*, 1869, p. 657).

**Auvergnose.** Presodic Subrang (3) of auvergnase.

**Avezaciase.** Calcimiric Section (3) of the permirlic Rang (1) of the dopyric Section (2) of sverigare, the polmitic Order (3) of dofemane, Class IV. From avezacite, from Avezac-Prat, Pyrenees (Lacroix, *C. R. VIII, Cong. Géol. Int.*, p. 832, 1901.

**Avezacose.** Magnesiferrous Subrang (3) of avezaciase.

B.

**Baltimorase.** Permirlic Rang (1) of marylandiare, the dopyric Section (2) of maorare, the perpolic Order (1) of perfemane, Class V. From pyroxenite of Johnny Cake Road, Baltimore County, Md. (G. H. Williams, *Am. Geol.* VI, 41, 1890).

**Baltimoriase.** Domiric Section (2) of baltimorase.

**Baltimorose.** Domagnesic Subrang (2) of baltimoriase.

**Bandase.** Docalcic Rang (4) of austrare, the quardofelic Order (4) of dosalane, Class II. From andesite of Bandai San, Japan (Nishiyama, *Rep. Géol. Sur. Jap.* 1887. *Cf. Neu. Jb.* 1890, II, p. 102).

**Bandose.** Presodic Subrang (3) of bandase.

**Basalt.** A dark colored, non-porphyritic, aphanitic igneous rock, without vitreous lustre.

**Beemerose.** Sodipotassic Subrang (3) of miaskase, the peralkalic Rang (1) of russare, the lendofelic Order (6) of persalane, Class I. From nephelite-syenite of Beemerville. N. J. (Iddings, *Bull. 150, U. S. G. S.*, 211, 1898).

**Beerbachose.** Persodic Subrang (5) of andase, the alkalicalcic Rang (3) of germanare, the perfelic Order (5) of dosalane, Class II. From beerbachite (Chelius, *Not. Bl. Ver. Erdk. Darmstadt* (4) XIII, 3 1892. Anal. *cf. Erl. geol. Kte. Hessen*, IV Lief. 39, 1896).

**Belcherose.** Permagnesic Subrang (1) of the domiric Section (2) of the permirlic Rang (1) of the dopyric Section (2) of hungarare, the perpolic Order (1) of dofemane, Class IV. From cortlandtite of Belchertown, Mass. (Emerson, *Mon. U. S. G. S.* XXIX, p. 347, 1898).

**Belgare.** Doquaric Order (2) of persalane, Class I. From Belgium.

**Bergenase.** Permirlic Rang (1) of bergeniare.

**Bergeniare.** Perpyric Section (1) of sverigare, the polmitic Order (3) of dofemane, Class IV. From Bergen, Norway.

**Bergeniase.** Permiric Section (1) of bergenase.

**Bergenose.** Magnesiferrous Subrang (3) of bergeniase.

**Bohemare.** Dolenic Order (8) of salfemane, Class III. From Bohemia.

**Borolanose.** Sodipotassic Subrang (3) of essexase, the domalkalic Rang (2) of norgare, the lendofelic Order (6) of dosalane, Class II. From borolanite, from Borolan, Scotland. (Howe and Teall, *Tr. R. Soc. Edinb.* XXXVII, Pt. I, 178, 1893).

**Brandbergiase.** Calcimiric Section (3) of the permirlic Rang (1) of the perpyric Section (1) of scotare, the dopolic Order (2) of dofemane, Class IV. From pyroxenite of Brandberget, Norway (Brögger, *Q. J. G. S.*, L. p. 31, 1894).

**Brandbergose.** Domagnesic Subrang (2) of brandbergiase.

**Britannare.** Quardofelic Order (4) of persalane, Class I. From Britannia, Great Britain.

## C.

**Calcimiric.** Equally calcic and miric, or nearly so, $\frac{MgO + FeO}{CaO} < \frac{5}{3} > \frac{3}{5}$ (p. 137).

**Campanare.** Dolenic Order (8) of dosalane, Class II. From Campania, Italy.

**Camptonase.** Alkalicalcic Rang (3) of gallare, the perfelic Order (5) of salfemane, Class III. From camptonite of Campton, N. H. (Rosenbusch, *Mikr. Phys*, 333, 1887).

**Camptonose.** Dosodic Subrang (4) of camptonase (Anal. Mount Ascutney, *Bull, 148, U. S. G. S.* 70, 1897).

**Canadare.** Perfelic Order (5) of persalane, Class I. From Canada.

**Canadase.** Percalic Rang (5) of canadare. From anorthosites of Canada.

**Caroliniare.** Perpyric Section (1) of maorare, the perpolic Order (1) of perfemane, Class V. From Carolina.

**Casselase.** Permirlic Rang (1) of the domolic Section (4) of scotare, the dopolic Order (2) of dofemane, Class IV. From basalt of Oberleinleiter, Cassel (Leppla and Schwager, *Geogn. Jh. Cassel*, I, p. 69, 1888).

**Casseliase.** Domiric Section (2) of casselase.

**Casselose.** Domagnesic Subrang (2) of casseliase.

**Cecilose.** Domagnesic Subrang (2) of websteriase, the domiric Section (2) of websterase, the permirlic Rang (1) of caroliniare, the perpyric Section (1) of maorare, the perpolic Order (1) of perfemane, Class V. From websterite of Oakwood, Cecil County, Md. (Leonard, *Bull. 168, U. S. G. S.* 43, 1900).

**Champlainase.** Permirlic Rang (1) of champlainore.

**Champlainiase.** Permiric Section (1) of champlainase.

**Champlainore.** Tilhemic Suborder (3) of adirondackare.

**Chloric.** Characterized by the presence of chlorine.

**Chlorsulphic.** Having equal or nearly equal proportions of Cl and $SO_3$. $\frac{Cl}{SO_3} < \frac{5}{3} > \frac{3}{5}$ (p. 140).

**Chotase.** Peralkalic Rang (1) of bohemare, the dolenic Order (8) of salfemane, Class III. From leucitite of Bearpaw Peak, Choteau County, Montana (Weed and Pirsson, *Am. Jour. Sci.* II, 147, 1896).

**Chotose.** Dopotassic Subrang (2) of chotase.

**Ciminose.** Dopotassic Subrang (2) of monzonase, the domalkalic Rang (2) of germanare, the perfelic Order (5) of dosalane, Class II. From ciminite (Washington, *Jour. Geol.*, IV, 838, 1896. Anal. *Am. Jour Sci.* IX, 44, 1900).

**Class.** Division of igneous rocks based on the relative proportions of salic and femic standard minerals.

**Coarse-grained.** Having the constituent grains averaging more than 5 millimeters in diameter.

**Coloradase.** Alkalicalcic Rang (3) of britannare, the quardofelic Order (4) of persalane, Class I. From Colorado laccoliths (Cross, *14th Ann. Rep. U. S. G. S.* 225 ff. 1894).

**Columbare.** Quarfelic Order (3) of persalane, Class I. From Columbia, United States.

**Cookose.** Domagnesic Subrang (2) of minnesotiase, the permiric Section (1) of minnesotase, the permirlic Rang (1) of minnesotiare, the perolic Section (1) of hungarare, the perpolic Order (1) of dofemane, Class IV. From hypersthene-gabbro of Gunflint Lake, Cook County, Minn. (Bayley, *Jour. Geol.* III, p. 10, 1895).

**Corsase.** Percalcic Rang (5) of germanare, the perfelic Order (5) of dosalane, Class II. From corsite (Collomb, 1853, *cf.* J. Roth, *Chem. Geol.* II, 199, 1887).

**Cortlandtase.** Permirlic Rang (1) of the domolic Section (4) of hungarare, the perpolic Order (1) of dofemane, Class IV. From cortlandtite (G. H. Williams, *A. J. S.*, XXXI, p. 30, 1886).

**Cortlandtiase.** Permiric Section (1) of cortlandtase.

**Cortlandtose.** Permagnesic Subrang (1) of cortlandtiase.

**Covose.** Dosodic Subrang (4) of albanase, the domalkalic Rang (2) of bohemare, the dolenic Order (8) of salfemane, Class III. From ijolite of Magnet Cove, Ark. (Washington, *Bull. Geol. Soc. Am.*, XI, p. 399, 1900. Not from covite, Washington, *Jour. Geol.*, IX, p. 612, 1901).

**Critical Mineral.** An abnormative mineral present in notable amount.

**Crystalline.** Holocrystalline.

**Crystallinity.** The degree of crystallization of a rock.

**Custerose.** Domagnesic Subrang (2) of cortlandtiase, the permiric Section (1) of cortlandtose, the permirlic Rang (1) of the domolic Section (4) of hungarare, the perpolic Order (1) of dofemane, Class IV. From peridotite of Silver Cliff, Custer County, Colo. (Cross, *17th Ann. Rep. U. S. G. S.*, II, 284, 1896).

## D

**Dacase.** Domalkalic Rang (2) of austrare, the quardofelic order (4) of dosalane. Class II. From dacite of ancient Dacia.

**Dacose.** Dosodic Subrang (4) of dacase.

**Dargase.** Peralkalic Rang (1) of belgare, the doquaric order (2) of persalane, Class I. From Dargo, Victoria, Australia, transitional rocks between granite and intrusive quartz veins. Described by Howitt.

**Dellenose.** Dopotassic Subrang (2) of toscanase, the domalkalic Rang (2) of britannare, the quardofelic Order (4) of persalane, Class I. From dellenite (Brögger, *Eruptivgest Krist. Geb.* II, 59, note, 1895. Anal. Svenonius, *Geol. För Stock.* Förh. X, 273, 1888).

**Diorite.** A phanerocrystalline igneous rock composed of dominant hornblende with other ferromagnesian minerals and subordinate feldspar of any kind.

**Do**— (or **dom**). Prefix indicating that one factor dominates over another within the ratios $\frac{7}{1}$ and $\frac{5}{3}$ (p. 123).

**Docalcic.** Dominantly calcic. Of salic minerals when CaO' dominates over $K_2O' + Na_2O'$. $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5} > \frac{1}{7}$. Of femic minerals when CaO'' dominates over MgO + FeO. $\frac{MgO + FeO}{CaO''} < \frac{3}{5} > \frac{1}{7}$ (p. 137).

**Dofelic.** Dominantly felic, having normative feldspar dominant over normative quartz or lenads. $\frac{Q \text{ or } L}{F} < \frac{3}{5} > \frac{1}{7}$.

**Dofemane.** Class IV of igneous rocks, having femic minerals dominant over salic. $\frac{Sal}{Fem} < \frac{3}{5} > \frac{1}{7}$ (p. 167).

**Dofemic.** Dominantly femic, having femic minerals dominant over salic. $\frac{Sal}{Fem} < \frac{3}{5} > \frac{1}{7}$ (p. 128).

**Dofemone.** Subclass 1 of dofemane. $\frac{POM}{A} > \frac{7}{1}$.

**Doferrous.** Dominantly ferrous, having FeO dominant over MgO. $\frac{MgO}{FeO} \quad \frac{3}{5} > \frac{1}{7}$ (p. 138).

**Dohemic.** Dominantly hemic, having hemic minerals (magnetite, hematite,) dominant over tilic minerals (titanite, ilmenite, perofskite, rutile). $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$ (p. 135).

**Dolenic.** Dominantly lenic, having the lenads—leucite, nephelite, and the sodalites, dominant over feldspar. $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ (p. 132).

**Domagnesic.** Dominantly magnesic, having MgO dominant over FeO. $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$ (p. 138).

**Domalkalic.** Dominantly alkalic; of salic minerals when $K_2O' + Na_2O'$ dominates over CaO'. $\frac{K_2O' + Na_2O'}{CaO'} < \frac{7}{1} > \frac{5}{3}$ (p. 135). Of femic minerals when $K_2O''$ $+ Na_2O''$ dominates over MgO + FeO + CaO''. $\frac{MgO + FeO + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5} > \frac{1}{7}$ (p. 136).

**Dominant.** Said of a factor which dominates over another within the ratios $\frac{7}{1}$ and $\frac{5}{3}$. Used in connection with a fivefold comparison (p. 122).

**Domiric.** Dominantly miric, having MgO + FeO dominant over CaO''. $\frac{MgO + FeO}{CaO''} < \frac{7}{1} > \frac{5}{3}$ (p. 137).

**Domirlic.** Dominantly mirlic, having MgO + FeO + CaO'' dominant over $K_2O''$ $+ Na_2O''$. $\frac{MgO + FeO + CaO''}{K_2O + Na_2O''} < \frac{7}{1} > \frac{5}{3}$ (p. 136).

**Domitic.** Dominantly mitic, having mitic minerals (magnetite, hematite, ilmenite, titanite, etc.) dominant over polic minerals (pyroxene, olivine, akermanite). $\frac{PO}{M} < \frac{3}{5} > \frac{1}{7}$ (p. 134).

**Domolic.** Dominantly olic, having normative olivine and akermanite dominant over normative pyroxenes. $\frac{P}{O}<\frac{3}{5}>\frac{1}{7}$ (p. 134).

**Donelic.** Dominantly nelic, having nelic minerals (nephelite, leucite,) dominant over sonic minerals (sodalite, noselite). $\frac{\text{ne, lc}}{\text{so, no}}<\frac{7}{1}>\frac{5}{3}$ (p. 139).

**Dopolic.** Dominantly polic, having polic minerals (pyroxene, olivine,) dominant over mitic minerals (magnetite, ilmenite, etc.). $\frac{PO}{M}<\frac{7}{1}>\frac{5}{3}$ (p. 133).

**Dopotassic.** Dominantly potassic, having $K_2O$ dominant over $Na_2O$. $\frac{K_2O}{Na_2O}<\frac{7}{1}>\frac{5}{3}$ (p. 137).

**Dopyric.** Dominantly pyric, having normative pyroxene dominant over normative olivine and akermanite. $\frac{P}{O}<\frac{7}{1}>\frac{5}{3}$ (p. 134).

**Doquaric.** Dominantly quaric, having normative quartz dominant over normative feldspar. $\frac{Q}{F}<\frac{7}{1}>\frac{5}{3}$ (p. 132).

**Dosalane.** Class II of igneous rocks, having salic minerals dominant over femic. $\frac{\text{Sal}}{\text{Fem}}<\frac{7}{1}>\frac{5}{3}$ (p. 167).

**Dosalic.** Dominantly salic, having the salic minerals dominant over the femic. $\frac{\text{Sal}}{\text{Fem}}<\frac{7}{1}>\frac{5}{3}$ (p. 128).

**Dosalone.** Subclass 1 of dosalane. $\frac{QFL}{CZ}>\frac{7}{1}$ .

**Dosodic.** Dominantly sodic, having $Na_2O$ dominant over $K_2O$. $\frac{K_2O}{Na_2O}<\frac{3}{5}>\frac{1}{7}$ (p. 137).

**Dosonic.** Dominantly sonic, having sonic minerals (sodalite, noselite,) dominant over nelic minerals (nephelite, leucite). $\frac{\text{ne, lc}}{\text{so, no}}<\frac{3}{5}>\frac{1}{7}$ (p. 139).

**Dotilic.** Dominantly tilic, having tilic minerals (titanite, ilmenite, etc.) dominant over hemic minerals (magnetite, hematite). $\frac{H}{T}<\frac{3}{5}>\frac{1}{7}$ (p. 135).

**Dunase.** Permirlic Rang (1) of maoriare, the perolic Section (5) of maorare, the perpolic Order (1) of perfemane, Class V. From dunite (v. Hochstetter, *Geol. v. Neu-Zeeland.* Wien, 1864, 218).

**Duniase,** Permiric Section (1) of dunase.

**Dunose.** Permagnesic Subrang (1) of duniase.

## E

**Essexase.** Domalkalic Rang (2) of norgare, the lendofelic Order (6) of dosalane Class II. From essexite (Sears, *Bull. Essex Inst.* XXIII, 2, 1891).

**Essexose.** Dosodic Subrang (4) of essexase (Anal. Dittrich in Rosenbusch, *Elemente*, 172, 1898, and Washington, *Jour. Geol.*, VII, 57, 1899).

**Etindase.** Alkalicalcic Rang (3) of kamerunare, the lenfelic Order (7) of salfemane, Class III. From hauynophyre of Etinde Volcano, Kamerun (Esch, *Sb. Berl. Akad.* 1901, 299).

**Etindose.** Dosodic Subrang (4) of etindase.

**Eutaxitic fabric.** One in which different parts of the rock exhibit different fabrics or degrees of crystallization.

**Extreme.** Said of a factor that is present alone or in amount greater than 7:1 of the other factor (p. 122).

## F

**Fabric.** The arrangement of the crystalline parts of a rock, or of the crystalline and non-crystalline parts.

**Family.** Any group of rocks developed from the same magma by processes of differentiation.

**Fel.** Syllable mnemonic of feldspar (p. 132).

**Feldspar-leucophyre.** A leucophyre with feldspar phenocrysts of any kind.

**Feldspar-melaphyre.** A melaphyre with feldspar phenocrysts of any kind.

**Feldsparphyre.** A porphyry with feldspar phenocrysts of any kind.

**Feldspar-vitrophyre.** A vitrophyre with feldspar phenocrysts of any kind.

**Felic.** Having the properties of, or containing, the feldspars (p. 132).

**Felsi.** Microfelsitic, microscopically aphanitic and homogeneous, but not isotropic glass (p. 173).

**Felsite.** An aphanitic igneous rock, non-porphyritic and light colored, without vitreous luster.

**Felsitic.** Having aphanitic texture.

**Felso.** Megascopically felsitic, megascopically aphanitic, but not glassy (p. 173).

**Fem.** Term mnemonic of the second group of standard minerals, including non-aluminous ferromagnesian and calcic silicates, silicotitanates and non-siliceous and non-aluminous minerals (p. 116).

**Femic.** Having the character of, or belonging to, the second (fem) group of standard minerals (p. 116).

**Femic abnormative mode.** An abnormative mode in which the critical minerals are femic.

**Femphyri.** Microscopically porphyritic with femic phenocrysts (p. 173).

**Femphyric.** Porphyritic with femic phenocrysts (p. 173).

**Femphyro.** Megascopically porphyritic with femic phenocrysts (p. 173).

**Fergusose.** Dopotassic Subrang (2) of laurdalase, the peralkalic Rang (1) of norgare, the lendofelic Order (6) of dosalane, Class II. From pseudoleucite-syenite of of Shonkin Creek, Fergus County, Montana. (Pirrson, *Bull. 148, U. S. G.S.* 154 1897.)

**Fine-grained.** Having the constituent grains averaging less than one millimeter.

**Finnare.** Perlenic Order (9) of salfemane, Class III. From Finland.

**Fluidal fabric.** Parallel fabric, showing evidence of flow.

## G

**Gabbro.** Phanerocrystalline igneous rock composed of dominant ferromagnesian minerals other than hornblende, with feldspar of any kind.

**Gallare.** Perfelic Order (5) of salfemane, Class III. From Gallia, France.

**Germanare.** Perfelic Order (5) of dosalane, Class II. From Germania, Germany.

**Gordonase.** Percalcic Rang (5) of hispanare, the quarfelic Order (3) of dosalane, Class II. From quartz-diorite of Sweden, Gordon County, Georgia. (*Bull 168, U. S. G. S.* 55, 1900).

**Grad.** (Old form of grade.) Division of Subrang based on the proportions of minerals of the subordinate group of standard minerals when present in notable amount.

**Grani.** Microscopically granitic, micrognanitic (p. 173).

**Granite.** A phanerocrystalline igneous rock, composed of quartz and feldspar, of any kind, with mica, hornblende, or other ferromagnesian minerals present in subordinate amount.

**Granitic.** Xenomorphic and hypautomorphic granular.

**Grano.** Megascopically granitic, megagranitic (p. 173).

**Granularity.** The magnitude of the grain of a rock.

**Graphi.** Micrographic (p. 173).

**Graphic.** A fabric in which two minerals mutually inclose one another by interpenetration (granophyric fabric in the sense of Rosenbusch).

**Grapho.** Megagraphic (p. 173).

**Grorudose.** Sodipotassic Subrang (3) of pantellerase, the peralkalic Rang (1) of austrare, the quardofelic Order (4) of dosalane, Class II. From grorudite (Brögger, *Eruptivgest. Krist. Geb.* I, 5, 1894. Anal. on p. 48).

## H

**Habit.** Resemblance in general appearance, both in texture and mode.

**Harzose.** Sodipotassic Subrang (3) of tonalase, the alkalicalcic Rang (3) of austrare, the quardofelic Order (4) of dosalane, Class II. From tonalites and porphyries of Hartz Mts. (Lossen, *Jb. preus. geol. L. A.* for 1889. 266, 290, 309. 1892).

**Hem.** Syllable mnemonic of hematite and magnetite (p. 134).

**Hemic.** Having the properties of, or containing, the minerals hematite or magnetite.

**Hessase.** Docalcic Rang (4) of germanare, the perfelic Order (5) of dosalane, Class II. From gabbros of Hesse-Darmstadt. (Anal. Chelius, *Not. Blatt. Ver. Erdk.* XVIII, 24, 1897).

**Hessose.** Presodic Subrang (3) of hessase.

**Heterogeneous texture.** One produced by marked diversity of fabric.'

**Highwoodose.** Dopotassic Subrang (2) of umptekase, the peralkalic Rang (1) of germanare, the perfelic Order (5) of dosalane, Class II. From trachyte of Highwood Gap, Highwood Mts., Montana. (Pirsson, *Bull. 148, U. S. G. S.* 152, 1897).

**Hispanare.** Quarfelic Order (3) of dosalane, Class III. From Hispania, Spain.

**Holohyaline.** Wholly glassy, without crystals.

**Hornblende-leucophyre.** Leucophyre with hornblende phenocrysts.

**Hornblende-melaphyre.** Melaphyre with hornblende phenocysts.

**Hornblendite.** Phanerocrystalline igneous rock composed almost completely of hornblende, with little or no feldspar.

**Hornblendophyre.** Porphyry with hornblende phenocrysts.

**Hungarare.** Perpolic Order (1) of dofemane, Class IV. From Hungary.

**Hungariare.** Pyrolic Section (3) of hungarare.

**Hypohyaline.** Partly glassy.

### I.

**—i—** Inserted before suffix which indicates Class, Order, etc., to indicate that the rock belongs to a Section of one of these divisions; producing iane, iare, iase etc. (p. 164).

**——ic.** Suffix added to name of a mineral to indicate it is a varietal mineral (p. 170).

**Iivaarose.** Dosodic Subrang (4) of ijolase, the peralkalic Rang (1) of finnare, the perlenic Order (9) of salfemane, Class III. From ijolite of Iivaara, Finland (Hackman, *Bull. Com. Géol. Finl.* No. 11, 17, 1900).

**Ijolase.** Peralkalic Rang (1) of finnare, the perlenic Order (9) of salfemane, Class III. From ijolite (Ramsay and Berghell, *Geol. För. Stockh. Förh.* XIII, 304. 1891).

**Ijolose.** Persodic Subrang (5) of ijolase.

**Ilmenose.** Sodipotassic Subrang (3) of umptekase, the peralkalic Rang (1) of germanare, the perfelic Order (1) of dosalane, Class II. From porphyrites of Ilmenau, Thuringia (Loretz, *Jb. preus. geol. L. A.*, XIII, 135. 1893).

**Indeterminable Mode.** The mode of a rock which is not completely crystallized, or which for any reason does not permit the determination of all the notable component minerals.

**Italare.** Lenfelic Order (7) of dosalane, Class II. From Italy.

### J

**Janeirose.** Sodipotassic Subrang (3) of lujavrase, the peralkalic Rang (1) of italare, the lenfelic Order (7) of dosalane, Class II. From tinguaite of Rio Janeiro, Brazil. (Anal., by Jannasch in Rosenbusch, *Elemente*, 215, 1898).

**Judithose.** Sodipotassic Subrang (3) of laurdalase, the peralkalic Rang (1) of norgare, the lendofelic Order (6) of dosalane, Class II. From potash-tinguaite of Cone Butte, Judith Mts., Montana (Weed and Pirsson, *Am. Jour. Sci.*, II, 192, 1896).

### K

**Kallerudose.** Dosodic Subrang (4) of liparase, the peralkalic Rang (1) of britannare, the quardofelic Order (4) of persalane, Class I. From grorudite of Kallerud, Norway (Brögger, *Eruptivgest. Krist. Geb.* I, 48, 1894).

**Kalteniase.** Permiric Section (1) of the permirlic Rang (1) of the perolic Section (5) of scotare, the dopolic Order (2) of dofemane, Class IV. From biotite-peridotite of Kaltenthal, Hartz Mts. (Koch, *Zeits. deut. geol. Ges.*, XLI, 165, 1889).

**Kaltenose.** Magnesiferrous Subrang (3) of kalteniase.

**Kamerunare.** Lenfelic Order (7) of salfemane, Class III. From Kamerun, Africa.

**Kamerunase.** Domalkalic Rang (2) of kamerunare.

**Kamerunose.** Dosodic Subrang (4) of kamerunase (Anals. nephelinites of Etinde Volcano, Kamerun (Esch, *Sb. preus. Akad.*, 1901, 299).

**Kedabekase.** Percalcic Rang (5) of gallare, the perfelic Order (5) of salfemane, Class III. From kedabekite (E. C. Federof, *Ann. Inst. Agron. Mosc.*, VII, Heft 1, 1901).

**Kentallenose.** Sodipotassic Subrang (3) of camptonase, the alkalicalcic Rang (3) of gallare, perfelic Order (5) of salfemane, Class III. From kentallenite (Hill and Kynaston, *Q. J. G. S.*, LVI, 537, 1900).

**Kilauase.** Domalkalic Rang (2) of gallare, the perfelic Order (5) of salfemane, Class III. From basalts of Kilauea, Hawaii (Silvestri, *Boll. Com. Geol. Ital.*, XIX, 178, 181, 1888).

**Kilauose.** Dosodic Subrang (4) of kilauase.

## L

**Labradorase.** Docalcic Rang (4) of canadare, the perfelic Order (5) of persalane, Class I. From Labrador.

**Labradorose.** Presodic Subrang (3) of labradorase.

**Lamarose.** Sodipotassic Subrang (3) of kilauase, the domalkalic Rang (2) of gallare, the perfelic Order (5) of salfemane, Class III. From absarokite of Lamar River, Yellowstone National Park (Iddings, *Jour. Geol.*, III, 938, 1895).

**Lappare.** Perlenic Order (9) of dosalane, Class II. From Lapland.

**Lassenose.** Dosodic Subrang (4) of toscanase, the domalkalic Rang (2) of britannare, the quardofelic Order (4) of persalane, Class I. From dacite of Lassen Peak, California (Diller, *Bull. 150, U. S. G. S.*, 218, 1898).

**Laugenase.** Peralkalic Rang (1) of tasmanare, the lenfelic Order (7) of persalane, Class I. From foyaite and nephelite-porphyry of Laugendal, Norway (Brögger, *Zeit. Kryst.* XVI., 41, 1890).

**Laugenose.** Dosodic Subrang (4) of laugenase.

**Laurdalase.** Peralkalic Rang (1) of norgare, the lendofelic Order (6) of dosalane, Class II. From laurdalite (Brögger, *Zeit. Kryst.* XVI, 32, 1890).

**Laurdalose.** Dosodic Subrang (4) of laurdalase.

**Laurvikose.** Dosodic Subrang (4) of pulaskase, the domalkalic Rang (2) of canadare, the perfelic Order (5) of persalane, Class I. From laurvikite (Brögger, *Zeit. Kryst.*, XVI, 30, 1890).

**Lebachose.** Perpotassic Subrang (1) of liparase, the peralkalic Rang (1) of britannare, the quardofelic Order (4) of persalane, Class I. From porphyries of localities on Blatt Lebach, Prussia (Weiss and Grebe, *Erl. geol. K'te. Preuss. Blatt Lebach*, 30, 1899).

**Len.** Syllable mnemonic of leucite and nephelite, including sodalite and noselite, the feldspathoids (p. 132).

**Lenad.** One of the standard minerals, leucite, nephelite, sodalite, or noselite (p. 132).

**Lenic.** Having the character of, or belonging to, the group of lenads.

**Lendofelic.** Having normative feldspars dominant over lenads. $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ (p. 132).

**Lenfelic.** Having normative feldspars and lenads in equal or nearly equal proportions. $\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$ (p. 132).

**Leucite-leucophyre.** A leucophyre with leucite phenocrysts.

**Leucite-melaphyre.** A melaphyre with leucite phenocrysts.

**Leucitophyre.** A porphyry with leucite phenocrysts.

**Leucophyre.** A porphyritic igneous rock, with aphanitic, light-colored groundmass, and with phenocrysts of any kind.

**Lherzase.** Permirlic Rang (1) of pyreniare, the perolic Section (5) of hungarare, the perpolic Order (1) of dofemane, Class IV. From lherzolite (Lelièvre, 1787).

**Lherziase.** Permiric Section (1) of lherzase.

**Lherzose.** Permagnesic Subrang (1) of lherziase (Anal. Lacroix, *cf. Neu. Jb.*, 1895, II, 267).

**Limburgase.** Alkalicalcic Rang (3) of portugare, the lendofelic Order (6) of salfemane, Class III. From limburgite (Rosenbusch, *Mikr. Phys.*, 1872).

**Limburgose.** Dosodic Subrang (4) of limburgase (Anal. Möller, *Neu. Jb.*, 1888, I, 112).

**Liparase.** Peralkalic Rang (1) of britannare, the quardofelic Order (4) of persalane, Class I. From liparite.

**Liparose.** Sodipotassic Subrang (3) of liparase.

**Lujavrase.** Peralkalic Rang (1) of italare, the lenfelic Order (7) of dosalane, Class II. From lujavrite (Ramsay, *Fennia*, XI, Pt. 2, 89, 1894).

**Lujavrose.** Dosodic Subrang (4) of lujavrase (Anal. Hackman, *op. cit.*, p. 132).

## M.

**Madupose.** Dopotassic Subrang (2) of ijolase, the peralkalic Rang (1) of finnare, the perlenic Order (9) of salfemane, Class III. From madupite (Cross, *Am. Jour. Sci.*, IV, 129, 1897; Anal., p. 130).

**Magdeburgose.** Dopotassic Subrang (2) of alaskase, the peralkalic Rang (1) of columbare, the quarfelic Order (3) of persalane, Class I. From quartz-porphyries of Magdeburg (Klockmann, *Jb. pr. geol. R. A.*, XI, 192, 1892).

**Magnesiferrous.** Equally magnesic and ferrous, or nearly so. $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ (p. 138).

**Malignase.** Peralkalic Rang (1) of kamerunare, the lenfelic Order (7) of salfemane, Class III. From malignite (Lawson, *Bull. Dep. Geol. Univ. Cal.*, I, 340, 1896).

**Malignose.** Dosodic Subrang (4) of malignase (Anal. *op. cit.*, pp. 356, 359).

**Maorare.** Perpolic Order (1) of perfemane, Class V. From Maori (natives of New Zealand).

**Maoriare.** Perolic Section (5) of maorare.

**Mariciase.** Permiric Section (1) of websterase, the permirlic Rang (1) of caroliniare, the perpyric Section (1) of maorare, the perpolic Order (1) of perfemane, Class V. From enstatite-pyroxenite of Central Marico District, Vaal Colony. (Henderson, *Inaug. Diss.*, London, 1898, 39).

**Maricose.** Permagnesic Subrang (1) of mariciase.

**Mariposose.** Persodic Subrang (5) of toscanase, the domalkalic Rang (2) of britannare, the quardofelic Order (4) of persalane, Class I. From aplite of Mariposa County, California (Turner, *Jour. Geol.*, III, 403, 1895).

**Mariupolose.** Persodic Subrang (5) of miaskase, the peralkalic Rang (1) of russare, the lendofelic Order (6) of persalane, Class I. From mariupolite (Morozewicz, *T. M. P. M.*, XXI, 244, 1902).

**Marquettiase.** Permiric Section (1) of texase, the permirlic Rang (1) of texiare, the pyrolic Section (3) of scotare, the dopolic Order (2) of dofemane, Class IV. From peridotite of Opin Lake, Marquette Region, Mich. (Van Hise and Bayley, *15th Ann. Rep. U. S. G. S.*, 511, 1895).

**Marquettose.** Domagnesic Subrang (2) of marquettiase.

**Marylandiare.** Dopyric Section (2) of maorare, the perpolic order (1) of perfemane, Class V. From Maryland.

**Medium-grained.** Having the constituent grains averaging between one and five millimeters.

**Melaphyre.** A porphyritic igneous rock, with aphanite dark-colored groundmass, and with phenocrysts of any kind.

**Miaskase.** Peralkalic Rang (1) of russare, the lendofelic order (6) of persalane, Class I. From miaskite (G. Rose, *Reise n. d. Ural*, II, 48, 1842).

**Miaskose.** Dosodic Subrang (4) of miaskase (Anal. Karpinsky, *Guide Exc., VII Cong. Géol. Int.*, V, 22, 1897).

**Mica-leucophyre.** A leucophyre with mica phenocrysts.

**Mica-melaphyre.** A melaphyre with mica phenocrysts.

**Micaphyre.** A porphyry with mica phenocrysts.

**Microcryptocrystalline.** Having the constituent grains individually invisible by the microscope, but whose presence is recognizable by the exhibition of aggregate polarization between crossed nicols.

**Microcrystalline.** Holocrystalline, the grains visible microscopically.

**Microlitic glassy texture.** A texture in which the phenocrysts are microscopic in size and the groundmass is glassy.

**Mihalose.** Dopotassic Subrang (2) of alsbachase, the domalkalic Rang (2) of columbare, the quarfelic Order (3) of persalane, Class I. From rhyolites of Nagy-Mihaly, Hungary (v. Muraközy, *Föld. Közl*, XXIII, 54, 1892).

**Minnesotase.** Permirlic Rang (1) of minnesotiare.

**Minnesotiare.** Perpyric Section (1) of hungarare, the perpolic Order (1) of dofemane, Class IV. From hypersthene-gabbro of Gunflint Lake, Minnesota (Bayley, *Jour. Geol.*, III, 10, 1895).

**Minnesotiase.** Permiric Section (1) of minnesotase.

**Mir.** Syllable mnemonic of magnesia and ferrous iron (p. 136).

**Miric.** Characterized by presence of MgO and FeO.

**Mirl.** Syllable mnemonic of magnesia, ferrous iron, and lime (p. 136).

**Mirlic.** Characterized by presence of MgO, FeO, and CaO.

**Mit.** Syllable mnemonic of magnetite, ilmenite, and titanite, and including all minerals of the second subgroup of femic minerals (p. 133).

**Mitic.** Adjective referring to the above mentioned minerals.

**Modal.** Relating to mode.

**Modal variety.** A rock having a development of the subordinate minerals slightly different from the norm.

**Mode.** The actual mineral composition of a rock. Opposed to norm, with which it may or may not coincide.

**Monchiquase.** Domalkalic Rang (2) of portugare, the lendofelic Order (6) of salfemane. Class III. From monchiquite (Hunter and Rosenbusch, *T. M. P. M.*, XI, 447, 1890).

**Monchiquose.** Dosodic Subrang (4) of monchiquase (Anal. *op. cit.*, p. 454).

**Monzonase.** Domalkalic Rang (2) of germanare, the perfelic Order (5) of dosalane, Class II. From monzonite (Brögger, *Eruptivgest. Krist. Geb.*, II, 21, 1895).

**Monzonose.** Sodipotassic Subrang (3) of monzonase (Anal. *op. cit.*, p. 24).

## N

**Negligible.** Term applied to the amount of any chemical or mineral factor when it is less than one-eighth of the group of factors under consideration (p. 122).

**Nel.** Syllable mnemonic of nephelite and leucite (p. 139).

**Nelic.** Having the properties of, or containing, normative nephelite or leucite.

**Nephelite-leucophyre.** Leucophyre with nephelite phenocrysts.

**Nephelite-melaphyre.** Melaphyre with nephelite phenocrysts.

**Nephelitophyre.** Porphyry with nephelite phenocrysts.

**Nordmarkase.** Peralkalic Rang (1) of canadare, the perfelic Order (5) of persalane, Class I. From nordmarkite (Brögger, *Zeit. Kryst.*, XVI, 55, 1890. Anal. *op. cit.*, II and III, 54).

**Nordmarkose.** Dosodic Subrang (4) of nordmarkase.

**Norgare.** Lendofelic Order (6) of dosalane, Class II. From Norge, Norway.

**Norm.** The standard mineral composition of a rock, *i. e.*, the chemical composition expressed in terms of standard minerals. Opposed to mode, with which it may or may not coincide.

**Normative.** Relating to the norm. That which makes up the norm.

**Normative mode.** A mode in which the actual mineral composition is so nearly the same as the norm, or standard mineral composition, as calculated from the analysis, that either may be used to classify the rock correctly.

**Notable.** Term applied to the amount of any chemical or mineral factor when it is greater than one-eighth of the group of factors under consideration (p. 122).

**Noyangose.** Persodic Subrang (5) of liparase, the peralkalic Rang (1) of britannare, the quardofelic Order (4) of persalane, Class I. From quartz-porphyries of Noyang, Victoria, Australia (Howitt, *Tr. R. Soc. Vict.*, XX, 41, 1884).

## O

——**oid.** Suffix to indicate habit (p. 179).

**Ol.** Syllable mnemonic of olivine, embracing also akermanite (p. 133).

**Olic.** Having the properties of, or containing, normative olivine or akermanite.

**Olivine-leucophyre.** Leucophyre with olivine phenocrysts.

**Olivine-melaphyre.** Melaphyre with olivine phenocrysts.

**Olivinophyre.** Porphyry with olivine phenocrysts.

**Omeose.** Dopotassic Subrang (2) of liparase, the peralkalic Rang (1) of britannare, the quardofelic Order (4) of persalane, Class I. From granite of Omeo, Victoria, Australia (Howitt, *Tr. R. Soc. Vict.*, XXIV, 120, 1888).

——**one.** Suffix indicating Subclass (p. 164).

**Ontarare.** Dolenic Order (8) of persalane, Class I. From Ontario, Canada.

**Ophiti.** Microscopically ophitic (p. 173).

**Ophitic.** A special case of poikilitic fabric in which plagioclase crystals are inclosed in augite crystals, the former being large relatively to the latter.

**Ophito.** Megascopically ophitic (p. 173).

**Orbicular fabric.** A fabric in which certain of the components form rounded masses, distinct from the rest of the rock or the groundmass.

**Order.** A division of Subclass based on the relative proportions of the standard mineral subgroups in the preponderant group.

——**ore.** Suffix indicating Suborder (p. 164).

**Orendase.** Peralkalic Rang (1) of gallare, the perfelic Order (5) of salfemane, Class III. From orendite (Cross, *Am. Jour. Sci.*, IV, 123, 1897).

**Orendose.** Perpotassic Subrang (1) of orendase.

**Ornose.** Persodic Subrang (5) of camptonase, the alkalicalcic Rang (3) of gallare, the perfelic Order (5) of salfemane, Class III. From ornoite (Cederstrom, *Geol. För. Stockh. Förh.*, XV, 108, 1893).

——**ose.** Suffix indicating Subrang (p. 164).

——**ote.** Suffix indicating Subgrad (p. 164).

**Ourose.** Sodipotassic Subrang (3) of limburgase, the alkalicalcic Rang (3) of portugare, the lendofelic Order (6) of salfemane, Class III. From monchiquite of Rio do Ouro, Brazil (Hunter and Rosenbusch, *T. M. P. M.*, XI, p. 464, 1890).

P

**Pantellerase.** Peralkalic Rang (1) of austrare, the quardofelic Order (4) of dosalane Class II. From pantellerite (Förstner, *Boll. Com. Geol. Ital.*, 1881, p. 537).

**Pantellerose.** Dosodic Subrang (4) of pantellerase (Anal., Förstner, *Zeit. Kryst.*, VIII., p. 186, 1884).

**Paolase.** Permirlic Rang (1) of paoliare. From jacupirangite, of Jacupiranga, Sao Paolo, Brazil (Anal., Washington, *Jour. Geol.*, IX, p. 620, 1901).

**Paoliare.** Dopyric Section (2) of scotare, the dopolic Order (2) of dofemane, Class IV. From Sao Paolo, Brazil.

**Paoliase.** Calcimiric Section (3) of paolase.

**Paolose.** Domagnesic Subrang (2) of paoliase.

**Parallel fabric.** One in which tabular or prismatic crystals are arranged more or less regularly in parallel positions.

**Per——.** Prefix to indicate that a factor is present alone, or in extreme amount; that is, its ratio to another factor is $> \frac{7}{1}$ (p. 123).

**Peralkalic.** Extremely alkalic. Of salic minerals when $K_2O' + Na_2O'$ is more than seven times $CaO'$. $\frac{K_2O' + Na_2O'}{CaO'} > \frac{7}{1}$ (p. 135).

Of femic minerals when $K_2O'' + Na_2O''$ is more than seven times $MgO + FeO + CaO''$. $\frac{MgO + FeO + CaO''}{K_2O'' + Na_2O''} < \frac{1}{7}$ (p. 136).

**Percalcic.** Extremely calcic. Of salic minerals when $CaO'$ is more than seven times $K_2O' + Na_2O'$. $\frac{K_2O' + Na_2O'}{CaO'} < \frac{1}{7}$ (p. 135). Of femic minerals when $CaO''$ is more than seven times $MgO + FeO$. $\frac{MgO + FeO}{CaO''} < \frac{1}{7}$ (p. 137).

**Perfelic.** Extremely felic. When normative feldspar is more than seven times the normative quartz or lenads. $\frac{Q \text{ or } L}{F} < \frac{1}{7}$ (p. 132).

**Perfemane.** Class V of igneous rocks, having femic minerals extremely abundant. $\frac{Sal}{Fem} < \frac{1}{7}$ (p. 167).

**Perfemic.** Extremely femic. Having femic minerals more than seven times the salic. $\frac{Sal}{Fem} < \frac{1}{7}$ (p. 128).

**Perfemone.** Subclass 1 of perfemane. $\frac{POM}{A} > \frac{7}{1}$.

**Perferrous.** Extremely ferrous. When FeO is more than seven times MgO. $\frac{MgO}{FeO} < \frac{1}{7}$ (p. 138) .

**Perhemic.** Extremely hemic; having hemic minerals (magnetite, hematite) more than seven times the tilic minerals (ilmenite, titanite, perofskite, rutile). $\frac{H}{T} > \frac{7}{1}$ (p. 134).

**Peridotite.** A phanerocrystalline igneous rock composed almost wholly of olivine, with little or no feldspar.

**Perlenic.** Extremely lenic; having lenic minerals (leucite, nephelite, sodalite, noselite) more than seven times the felic minerals (feldspars). $\frac{L}{F} > \frac{7}{1}$ (p. 132).

**Permagnesic.** Extremely magnesic; having MgO more than seven times FeO. $\frac{MgO}{FeO} > \frac{7}{1}$ (p. 138).

**Permiric.** Extremely miric; having $MgO + FeO$ more than seven times $CaO'$. $\frac{MgO + FeO}{CaO'} > \frac{7}{1}$ (p. 136).

**Permirlic.** Extremely mirlic; having $MgO + FeO + CaO'$ more than seven times $K_2O' + Na_2O'$. $\frac{MgO + FeO + CaO'}{K_2O' + Na_2O'} > \frac{7}{1}$ (p. 136).

**Permitic.** Extremely mitic; having mitic minerals (magnetite, hematite, ilmenite titanite, perofskite, rutile) more than seven times the polic minerals (pyroxenes, olivine, akermanite). $\frac{PO}{M} < \frac{1}{7}$ (p. 134).

**Pernelic.** Extremely nelic; having nelic minerals (nephelite, leucite) more than seven times the sonic minerals (sodalite, noselite). $\frac{ne,\ lc}{so,\ no} > \frac{7}{1}$ (p. 139).

**Perolic.** Extremely olic; having olic minerals (olivine, akermanite) more than seven times the pyric minerals (pyroxenes). $\frac{P}{O} < \frac{1}{7}$ (p. 134).

**Perpolic.** Extremely polic, having polic minerals (pyroxenes, olivine, akermanite) more than seven times the mitic minerals (magnetite, hematite, ilmenite, titanite, etc.). $\frac{PO}{M} > \frac{7}{1}$ (p. 133).

**Perpotassic.** Extremely potassic, having $K_2O'$ more than seven times $Na_2O'$. $\frac{K_2O'}{Na_2O'} > \frac{7}{1}$ (p. 137).

**Perpyric.** Extremely pyric, having pyric minerals (pyroxenes) more than seven times the olic minerals (olivine, akermanite). $\frac{P}{O} > \frac{7}{1}$ (p. 134).

**Perquaric.** Extremely quaric; having normative quartz more than seven times the normative feldspar. $\frac{Q}{F} > \frac{7}{1}$ (p. 132).

**Persalane.** Class I of igneous rocks, having salic minerals extremely abundant. $\frac{Sal}{Fem} > \frac{7}{1}$ (p. 167).

**Persalic.** Extremely salic; having salic minerals more than seven times the femic. $\frac{\text{Sal}}{\text{Fem}} > \frac{7}{1}$ (p. 128).

**Persalone.** Subclass 1 of persalane. $\frac{\text{QFL}}{\text{CZ}} > \frac{7}{1}$.

**Persodic.** Extremely sodic, having $Na_2O'$ more than seven times $K_2O'$. $\frac{K_2O'}{Na_2O'} < \frac{1}{7}$ (p. 137).

**Personic.** Extremely sonic, having sonic minerals (sodalite, noselite) more than seven times the nelic minerals (nephetite, leucite). $\frac{\text{ne, lc}}{\text{so, no}} < \frac{1}{7}$ (p. 139).

**Pertilic.** Extremely tilic, having tilic minerals (ilmenite, titanite, perofskite, rutile) more than seven times the hemic minerals (magnetite, hematite). $\frac{\text{H}}{\text{T}} < \frac{1}{7}$ (p. 135).

**Phaneric.** Phanerocrystalline — megascopically holocrystalline.

**Phanerite.** A rock which is phanerocrystalline.

**Phlegrose.** Sodipotassic Subrang (3) of nordmarkase, the peralkalic Rang (1) of canadare, the perfelic order (5) of persalane, Class I. From trachytes of Phlegræan Fields, Naples, Italy (Anals. Washington *A. J. S.*, VIII, 287, 1900).

**Phyri.** Microporphyritic, having the phenocrysts not megascopically notable, or quite insignificant, but visible microscopically (p. 173).

**Phyro.** Megascopically porphyritic, having the phenocrysts visible to the naked eye (p. 173).

**Placerose.** Persodic Subrang (5) of tonalase, the alkalicalcic Rang (3) of austrare, the quardofelic Order (4) of dosalane, Class II. From granite of English Mountain, Placer County, Cal. (Lindgren, *Bull. 148, U. S. G. S.*, p. 212, Anal. E, 1897).

**Poikili.** Micropoikilitic (p. 173).

**Poikilo.** Megapoikilitic (p. 173).

**Pol.** Syllable mnemonic of the femic silicates: pyroxenes and olivine, including akermanite (p. 133).

**Polic.** Characterized by the presence of the femic silicates.

**Polmitic.** Having equal or nearly equal amounts of polic and mitic minerals. $\frac{\text{PO}}{\text{M}} < \frac{5}{3} > \frac{3}{5}$ (p. 133).

**Porphyritic texture.** One in which some crystals are so much larger than a number of others sufficient to form a matrix for the first, that the larger ones appear notably distinct from the matrix or groundmass. The groundmass may be uncrystallized, glass.

**Porphyry.** A porphyritic igneous rock having a groundmass and phenocrysts of any kind.

**Portugare.** Lendofelic Order (6) of salfemane, Class III. From Portugal.

**Pre**—— Prefix indicating the predominance of one factor over another in a ratio $> \frac{5}{3}$ (p. 123).

**Prealkalic.** Predominantly alkalic, of salic minerals when $\frac{K_2O' + Na_2O'}{CaO'} > \frac{5}{3}$ (p. 143). Of femic minerals when $\frac{MgO + FeO + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5}$ (p. 143).

**Precalcic.** Predominantly calcic. Of salic minerals when $\frac{K_2O'+Na_2O'}{CaO'}<\frac{3}{5}$ (p. 143). Of femic minerals when $\frac{MgO+FeO}{CaO'}<\frac{3}{5}$ (p. 144).

**Prechloric.** Predominantly chloric, having $\frac{Cl}{SO_3}>\frac{5}{3}$ (p. 140).

**Predominant.** Said of a factor which preponderates over another in any ratio greater than $\frac{5}{3}$. Used in connection with a threefold comparison (p. 123).

**Prefelic.** Predominantly felic, having normative feldspar predominant over normative quartz or lenads. $\frac{Q \text{ or } L}{F}<\frac{3}{5}$.

**Preferrous.** Predominantly ferrous, having $\frac{MgO}{FeO}<\frac{3}{5}$ (p. 138).

**Prelenic.** Predominantly lenic, having lenads predominant over normative feldspars. $\frac{L}{F}>\frac{5}{3}$ (p. 142).

**Premagnesic.** Predominantly magnesic, having $\frac{MgO}{FeO}>\frac{5}{3}$ (p. 138).

**Premiric.** Predominantly miric, having $\frac{MgO+FeO}{CaO'}>\frac{5}{3}$ (p. 144).

**Premirlic.** Predominantly mirlic, having $\frac{MgO+FeO+CaO'}{K_2O'+Na_2O'}>\frac{5}{3}$ (p. 143).

**Premitic.** Predominantly mitic, having mitic minerals (magnetite, ilmenite, titanite, etc.) predominant over polic minerals (pyroxene, olivine, akermanite). $\frac{PO}{M}<\frac{3}{5}$ (p. 141).

**Prenelic.** Predominantly nelic, having nelic minerals (nephelite, leucite) predominant over sonic minerals (sodalite, noselite). $\frac{ne,\ lc}{so,\ no}>\frac{5}{3}$ (p. 139).

**Preolic.** Predominantly olic, having olic minerals (olivine, akermanite) predominant over pyric minerals (pyroxenes). $\frac{P}{O}<\frac{3}{5}$ (p. 142).

**Prepolic.** Predominantly polic, having polic minerals (pyroxene, olivine, akermanite) predominant over mitic minerals (magnetite, ilmenite, titanite, etc.). $\frac{PO}{M}>\frac{5}{3}$ (p. 141).

**Prepotassic.** Predominantly potassic, having $\frac{K_2O'}{Na_2O'}>\frac{5}{3}$ (p. 137).

**Prepyric.** Predominantly pyric, having pyric minerals (pyroxenes) predominant over olic minerals (olivine, akermanite). $\frac{P}{O}>\frac{5}{3}$ (p. 142).

**Prequaric.** Predominantly quaric, having normative quartz predominant over normative feldspar. $\frac{Q}{F}>\frac{5}{3}$ (p. 142).

**Presodic.** Predominantly sodic, having $\frac{K_2O'}{Na_2O'}<\frac{3}{5}$ (p. 137).

**Presonic.** Predominantly sonic, having sonic minerals (sodalite, noselite) predominant over nelic minerals (nephelite, leucite). $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5}$ (p. 139).

**Presulphic.** Predominantly sulphic, having $\frac{\text{Cl}}{\text{SO}_3} < \frac{3}{5}$ (p. 140).

**Prismatic fabric.** One in which the crystals are mostly prismatic in shape.

**Prowersose.** Dopotassic Subrang (2) of kilauase, the domalkalic Rang (2) of gallare, the perfelic Order (5) of salfemane, Class III. From syenitic lamprophyre of Two Buttes, Prowers County, Colo. (Cross, *Bull. 148, U. S. G. S.*, p. 182, 1897).

**Pulaskase.** Domalkalic Rang (2) of canadare, the perfelic order (5) of persalane, Class I. From pulaskite (J. F. Williams, *Ark. Geol. Surv. Ann. Rep.* 1890, Vol. II, p. 56, 1891).

**Pulaskose.** Sodipotassic Subrang (3) of pulaskase (Anal. *op. cit.*, p. 70).

**Pyr.** Syllable mnemonic of pyroxenes (p. 133).

**Pyreniare.** Perolic Section (5) of hungarare, the perpolic Order (1) of dofemane, Class IV. From the Pyrenees Mountains.

**Pyric.** Characterized by the presence of normative pyroxenes.

**Pyrolic.** Having equal or nearly equal amounts of normative pyroxene and olivine or akermanite. $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$ (p. 134).

**Pyroxenite.** Phanerocrystalline igneous rock, composed almost entirely of pyroxene, with little or no feldspar.

## Q

**Quar.** Syllable mnemonic of quartz (p. 132).

**Quardofelic.** Having felic minerals (feldspar) dominant over normative quartz. $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$ (p. 132).

**Quarfelic.** Having equal or nearly equal amounts of normative quartz and feldspars. $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ (p. 132).

**Quaric.** Characterized by the presence of normative quartz.

**Quartz-leucophyre.** Leucophyre with quartz phenocrysts.

**Quartz-melaphyre.** Melaphyre with quartz phenocrysts.

**Quartzophyre.** Porphyry with quartz phenocrysts.

**Quartz-vitrophyre.** Vitrophyre with quartz phenocrysts.

## R

**Radiate fabric.** One in which tabular or prismatic crystals are arranged in more or less radiating directions.

**Rang.** (Old form of rank.) Division of Order based on the character of the chemical bases in the preponderant group of standard minerals.

**Riesenase.** Alkalicalcic Rang (3) of columbare, the quarfelic Order (3) of persalane, Class I. From granites of the Riesengebirge, Silesia (Milch, *Neu. Jb.*, B., Bd. XII, pp. 152–222. 1899).

**Riesenose.** Sodipotassic Subrang (3) of riesenase (Anal., *op. cit.*, pp. 168, 169, 180, 194, 210).

**Rockallase.** Peralkalic Rang (1) of atlantare, the quarfelic Order (3) of salfemane, Class III. From rockallite (Judd, *Tr. R. Irish Acad.*, Vol. XXXI, Pt. III, p. 54, 1897).

**Rockallose.** Persodic Subrang (5) of rockallase.

**Rossweinose.** Domagnesic Subrang (2) of the domiric Section (2) of wehrlase, the permirlic Rang (1) of hungariare, the pyrolic Section (3) of hungarare, the perpolic Order (1) of dofemane, Class IV. From gabbros of Rosswein, Saxony (Sachsse and Becker, *Land. Vers. Anst.*, XL, 1892. *Cf. Neu. Jb.*, II, 503, 1893).

**Russare.** Lendofelic Order (6) of persalane, Class I. From Russia.

## S

**Sagamose.** Prepotassic Subrang (1) of bandase, the docalcic Rang (4) of austrare, the quardofelic Order (4) of dosalane, Class II. From quartz-diorite of Sagami, Japan (Harada, *Die Jap. Inseln.* Berlin, 1890. 118).

**Sal.** Syllable mnemonic of the silico-aluminous non-ferromagnesian group of standard minerals, including quartz, feldspars, lenads, corundum and zircon (p. 116).

**Salemase.** Alkalicalcic Rang (3) of norgare, the lendofelic Order (6) of dosalane, Class II. From hornblende-gabbro of Salem Neck, Mass. (Washington, *Jour. Geol.*, VII, 63, 1899).

**Salemose.** Dosodic Subrang (4) of salemase.

**Salfemane.** Class III of igneous rocks; having salic and femic minerals in equal or nearly equal proportions. $\frac{\text{Sal}}{\text{Fem}} < \frac{5}{3} > \frac{3}{5}$ (p. 167).

**Salfemone.** Subclass 1 of Salfemane; having the polic and mitic minerals more than seven times the remaining femic minerals. $\frac{\text{POM}}{\text{A}} > \frac{7}{1}$.

**Salfemic.** Having salic and femic minerals in equal or nearly equal amounts. $\frac{\text{Sal}}{\text{Fem}} < \frac{5}{3} > \frac{3}{5}$ (p. 128).

**Salfemic abnormative mode.** An abnormative mode in which the critical minerals are both salic and femic.

**Salfemphyri.** Microscopically porphyritic, with both salic and femic phenocrysts (p. 173).

**Salfemphyric.** Porphyritic, with both salic and femic phenocrysts (p. 173).

**Salfemphyro.** Megascopically porphyritic, with both salic and femic phenocrysts (p. 173).

**Salic.** Having the characters of, or belonging to, the first (sal) group of standard minerals.

**Salic abnormative mode.** An abnormative mode, in which the critical minerals are salic.

**Salphyri.** Microscopically porphyritic, with salic phenocrysts (p. 173).

**Salphyric.** Porphyritic, with salic phenocrysts (p. 173).

**Salphyro.** Megascopically porphyritic, with salic phenocrysts (p. 173).

**Schlieric texture.** A streaked heterogeneous texture in which different parts of the rock exhibit differences in mineral composition, accompanied or not by textural differences.

**Scotare.** Dopolic Order (2) of dofemane, Class IV. From Scotland.

**Section.** Subdivision of any of the other taxonomic divisions, from Class to Subgrad.

**Shonkinose.** Sodipotassic Subrang (3) of monchiquase, the domalkalic Rang (2) of portugare, the lendofelic Order (6) of salfemane, Class VI. From shonkinite (Weed and Pirsson, *Bull. Geol. Soc. Am.*, Vol. VI, anal. p. 414, 1895).

**Shoshonose.** Sodipotassic Subrang (3) of andase, the alkalicalcic Rang (3) of germanare, the perfelic Order (5) of dosalane, Class II. From shoshonite (Iddings, *Jour. Geol.*, Vol. III, anal. p. 944, 1895).

**Sitkose.** Dosodic Subrang (4) of almerase, the alkalicalcic Rang (3) of hispanare, the quarfelic Order (3) of dosalane, Class II. From quartz-porphyry of Sitka, Alaska (Becker, *18th Ann. Rep. U. S. G. S.*, Pt. III, p. 45, 1898).

**Sodipotassic.** Having soda and potash in equal or nearly equal proportions. $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$ (p. 137).

**Son.** Syllable mnemonic of sodalite and noselite (p. 139).

**Sonic.** Having the properties of, or containing, the minerals sodalite and noselite.

**Sonnelic.** Having equal or nearly equal amounts of sonic minerals (sodalite, noselite) and nelic minerals (nephelite, leucite). $\frac{\text{ne, lc}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$ (p. 139).

**Spheri.** Microspherulitic, *i. e.*, having spherulites which are only visible microscopically (p. 173).

**Sphero.** Megaspherulitic, *i. e.*, having spherulites which are visible with the naked eye (p. 173).

**Spherulitic texture.** One composed of rounded masses or spherulites.

**Standard mineral.** One of the minerals or mineral molecules selected to express the chemical composition of an igneous rock.

**Standard mineral composition.** The composition of a rock expressed in terms of the standard minerals as calculated from the chemical analysis. The norm.

**Structure.** The larger features of rock bodies, such as columnar structure, platy parting, bedding, etc.

**Subclass.** Division of Class according to certain broad chemical differences in the preponderant standard mineral group.

**Subgrad.** Division of Grad, based on the chemical character of the minerals used in forming Grad.

**Suborder.** Division of Order.

**Subrang.** Division of Rang, based on the character of the chemical bases in the preponderant mineral subgroup used in forming Rang.

**Sulphic.** Characterized by the presence of $SO_3$.

**Sverigare.** Polmitic Order (3) of dofemane, Class IV. From Sverige, Sweden.

**Sverigiare.** Perolic Section (5) of sverigare.

**Syenite.** A phanerocrystalline igneous rock, composed of dominant feldspar of any kind, with subordinate amounts of mica, hornblende, pyroxene, or other minerals, and without noticeable amount of quartz.

## T.

**Tabergase.** Permirlic Rang (1) of sverigiare, the perolic Section (5) of sverigare, the polmitic Order (3) of dofemane, Class IV. From magnetite-olivinite of Taberg, Sweden (Sjögren, *Geol. För. Stockh. Förh.* III, p. 42, 1876).

**Tabergiase.** Permiric Section (1) of tabergase.

**Tabular fabric.** A fabric in which the minerals are largely tabular in shape.

**Tasmanare.** Lenfelic Order (7) of persalane, Class I. From Tasmania.

**Tehamose.** Sodipotassic Subrang (3) of alsbachase, the domalkalic Rang (2) of columbare, the quarfelic Order (3) of persalane, Class I. From rhyolite of Tehama County, Cal. (Diller, *Bull. 148, U. S. G. S.* p. 192, 1897).

**Texase.** Permirlic Rang (1) of texiare.

**Texiare.** Pyrolic Section (3) of scotare, dopolic Order (2) of dofemane, Class IV. From Texas.

**Texture.** The material features of rocks, exhibited by the mineral components, or by the groundmass of dense or glassy rocks, whether they are viewed megascopically or microscopically. *Cf.* structure.

**Til.** Syllable mnemonic of the titaniferous femic minerals: titanite and ilmenite, including perofskite and rutile (p. 134).

**Tilhemic.** Having equal or nearly equal proportions of tilic minerals (titanite, ilmenite, perofskite, rutile) and hemic minerals (magnetite, hematite), $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$ (p. 135).

**Tilic.** Having the characters of, or pertaining to, the titaniferous femic minerals.

**Tonalase.** Alkalicalcic Rang (3) of austrare, the quardofelic Order (4) of dosalane, Class II. From tonalite. (v. Rath, *Zeit. deut. geol. Ges.* Vol. XVI, p. 249, 1864).

**Tonalose.** Dosodic Subrang (4) of tonalase.

**Toscanase.** Domalkalic Rang (2) of britannare, the quardofelic Order (4) of persalane, Class I. From toscanite (Washington, *Jour. Geol.* Vol. V, p. 37, 1897.)

**Toscanose.** Sodipotassic Subrang (3) of toscanase.

**Trachi.** Microscopically trachytic, microtrachytic (p. 173).

**Tracho.** Megascopically trachytic, megatrachytic (p. 173).

**Trachytic fabric.** Panautomorphic, with tabular feldspars.

**Tuolumnose.** Persodic Subrang (5) of nordmarkase, the peralkalic Rang (1) of canadare, the perfelic Order (5) of persalane, Class I. From soda-syenite of Tuolumne County, Cal. (Turner, *Am. Geol.* Vol. XVII, p. 387, 1896).

**Type.** A rock which forms a standard by which to indicate identity in norm, mode and texture, or a close approximation to identity.

## U.

**Umptekase.** Peralkalic Rang (1) of germanare, the perfelic Order (5) of dosalane, Class II. From umptekite (Ramsay, *Fennia*, Vol. XI, p. 81, 1894).

**Umptekose.** Dosodic Subrang (4) of umptekase (Anal., *op. cit.*, p. 205).

**Urtase.** Peralkalic Rang (1) of lappare, the perlenic Order (9) of dosalane, Class II. From urtite (Ramsay, *Geol. För. Stockh. Förh.* XVIII, p. 463, 1896).

**Urtose.** Dosodic Subrang (4) of urtase.

**Uvaldiase.** Domiric Section (2) of texase, the permiric Rang (1) of texiare, the pyrolic section (3) of scotare, the dopolic Order (2) of dofemane, Class IV. From nephelite-basalt of Uvalde County, Texas. (Cross, *Bull. 168, U. S. G. S.* p. 62, G. and p. 63, I, 1900).

**Uvaldose.** Domagnesic Subrang (2) of uvaldiase.

## V.

**Vaalare.** Quardofelic Order (4) of salfemane, Class III. From Vaal Colony, Africa (Cohen, *Neu. Jb,* B. Bb., V, pp. 233, 245, 247, 1887).

**Vaalase.** Alkalicalcic Rang (3) of vaalare.

**Vaalose.** Dosodic Subrang (4) of vaalase.

**Valbonniase.** Permiric Section (1) of paolase, the permirlic Rang (1) of paoliare, the dopyric Section (2) of scotare, the dopolic Order (2) of dofemane, Class IV. From hornblendite of Vallée de Valbonne, Pyrenees Mts. (Lacroix, *Bull. Serv. Cte. Géol. Fr.*, XI, No. 71, 31, 1900).

**Valbonnose.** Permagnesic Subrang (1) of valbonniase.

**Varietal.** Having the character of, or producing, a variety of a mode.

**Variety.** A division of a mode, recognizing the presence of subordinate mineral components.

**Varingase.** Peralkalic Rang (1) of hispanare, the quarfelic Order (3) of dosalane, Class II. From grorudite of Varingskollen, Norway. (Brögger, *Zeit. Kryst.*, Vol. XVI, p. 66, 1890).

**Varingose.** Sodipotassic Subrang (3) of varingase.

**Venanziase.** Calcimiric Section (3) of lherzase, the permirlic Rang (1) of pyreniare, the perolic Section (5) of hungarare, the perpolic Order (1) of dofemane, Class IV. From venanzite (Sabatini, *Boll. Com. Geol. Ital.*, No. 3, 1898).

**Venanzose.** Domagnesic Subrang (2) of venanziase (Anal. Rosenbusch, *Sb. Berl. Akad.* 1899, 113).

**Vesuvase.** Domalkalic Rang (2) of campanare, the dolenic Order (8) of dosalane, Class II. From Mt. Vesuvius.

**Vesuvose.** Dopotassic Subrang (2) of vesuvase (Anal. by Washington, unpublished).

**Victorare.** Perquaric Order (1) of persalane, Class I. From quartz dikes of Victoria, Australia (Howitt, *Roy. Soc.*, Victoria, Jan. 17, 1887).

**Viezzenase.** Domalkalic Rang (2) of russare, the lendofelic Order (6) of persalane, Class I. From nephelite-syenite-porphyry of Viezzenathal, Predazzo, Tyrol (Osann and Hlawatsch, *T. M. P. M.*, XVIII, p. 560, 1898).

**Viezzenose.** Dosodic Subrang (4) of viezzenase.

**Vitri.** Microscopically glassy (p. 173).

**Vitro.** Megascopically glassy (p. 173).

**Vitrophyre.** Porphyritic glassy rock (Vogelsang, 1872).

**Vulcanose.** Persodic Subrang (5) of riesenase, the alkalicalcic Rang (3) of columbare, the quarfelic Order (3) of persalane, Class I. From vulcanite (Hobbs, *Zeit. deut. geol. Ges.*, XLV, p. 591, 1893, and *Bull. Geol. Soc. Am.* Vol. V., p. 601, 1894).

**Vulsinose.** Dopotassic Subrang (2) of pulaskase, the domalkalic Rang (2) of canadare, the perfelic Order (5) of persalane, Class I. From vulsinite (Washington, *Jour. Geol.*, IV, 547, 1896. Anal. p. 552).

**Vulturase.** Domalkalic Rang (2) of italare, the lenfelic Order (7) of dosalane, Class II. From hauynophyre of Melfi, Mte. Vulture, Italy.

**Vulturose.** Dosodic Subrang (4) of vulturase (Anal. Rammelsberg, *Zeit. deut. geol. Ges.*, XIII, 273, 1860).

W.

**Websterase.** Permirlic Rang (1) of caroliniare, the perpyric Section (1) of maorare, the perpolic Order (1) of perfemane, Class V. From websterite (G. H. Williams, *Am. Geol.*, Vol. VI, p. 44, 1890.

**Websteriase.** Domiric Section (2) of websterase.

**Websterose.** Permagnesic Subrang (1) of websteriase.

**Wehrlase.** Permirlic Rang (1) of hungariare, the pyrolic Section (3) of hungarare, the perpolic Order (1) of dofemane, Class IV. From wehrlite (Von Kobell, 1838).

**Wehrliase.** Permiric Section (1) of wehrlase.

**Wehrlose.** Domagnesic Subrang (2) of wehrliase (Anal. Merrill, *Proc. U. S. Nat. Mus.*, XVII, 652, 1895).

**Westphalose.** Persodic Subrang (5) of alaskase, the peralkalic Rang (1) of columbare, the quarfelic Order (3) of persalane, Class I. From quartz-keratophyres of Wesphalia (Mügge, *Neu. Jb.* B. B., VIII, 616, 632, 1893).

**Wyomingase.** Peralkalic Rang (1) of portugare, the lendofelic Order (6) ot salfemane, Class III. From wyomingite (Cross, *Am. Jour. Sci.*, IV, 120, 1897).

**Wyomingose.** Perpotassic Subrang (1) of wyomingase (Anal. *op. cit.*, III, 130).

Y.

**Yellowstonose.** Dosodic Subrang (4) of coloradase, the alkalicalcic Rang (3) of britannare, the quardofelic Order (4) of persalane, Class I. From rocks of the Yellowstone National Park (Iddings, *Mon. XXXII, U. S. G. S.*, Pt. II, 1899).

**Yukonose.** Persodic Subrang (5) of alsbachase, the domalkalic Rang (2) of columbare, the quarfelic Order (3) of persalane, Class I. From tonalite-aplite of Yukon River, Alaska (Spurr, *Bull. 168, U. S. G. S.*, 229, 1900).

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av

2 items in pocket